CORPS OF ENGINEERS, U. S. ARMY

LYNNHAVEN BAY AND INLET, VIRGINIA

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-348

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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1. Col. Gesler 2
2. Mr. Caldwell
3. Eaton

It appears that the W.E.S. has misconstrued "littoral current", and that what they generated under that name (see par. 14) should have been called "Chesapeake Bay Tidal Current." With a 5' high wave 150' long (prototype) running continuously at a substantial angle (see fig 4) a true littoral current was doubtless created.

The drift rate attained, 5,000 c.y. per tidal cycle, was obviously excessive. It is difficult to understand how W.E.S. would venture to predict relative efficiency of the various

(over)

plans tested based on only 16 tidal cycles. The fact that the model produced apparent stability after about 12 tidal cycles should in itself cast grave doubts as to validity of results.

Prediction of comparative shoaling rates for various plans is a doubtful practice under the most favorable conditions. In a model involving transport by wave action, with the model distorted 5 to 1 and the waves undistorted, such predictions have no foundation and could gravely mislead the designer.

RCZ

In a closed model, with distorted scale, can a true littoral current be developed in proper relation to prototype. Introduction of a circulating current in this model may have been the correction factor to produce a stable bed condition. What would have happened, though, if only half the circulation were used, and say, 1000 cu yds material per tidal cycle, instead of 5000. Are there not other combinations which would have produced the same "stable" conditions in the model but would have shown radically different results for the various plans studied.

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PREFACE

The model studies of Lynnhaven Bay and Inlet were authorized by the Office, Chief of Engineers, in correspondence dated 26 December 1945. The studies were conducted during the period July 1946-July 1950.

Personnel of the Waterways Experiment Station actively connected with the studies were Messrs. E. P. Fortson, Jr., G. B. Fenwick, H. B. Simmons, C. D. McKellar, and H. J. Rhodes.

CONTENTS

SUMMARY

The investigation reported herein was conducted to develop the most efficient design of inlet and interior channels to provide the desired volume of tidal flow into and out of Lynnhaven Bay, to determine the effectiveness of jetties in preventing shoaling of the inlet channel, and to observe the effects of jetties on the beaches adjacent to the inlet. Two models were used in the study: (a) a fixed-bed model, reproducing all Lynnhaven Bay and Inlet and a portion of Chesapeake Bay to scales of 1:800 horizontally and 1:80 vertically; (b) a movable-bed model, reproducing Lynnhaven Inlet and adjacent beaches, and offshore areas to about the -25-ft contour of depth in Chesapeake Bay, to scales of 1:400 horizontally and 1:80 vertically.

Tests indicated that (a) a channel 12 ft deep and 400 ft wide through Lynnhaven Inlet and across the outer bar will be adequate for tidal circulation to and from the interior bay system; (b) a channel through Long Creek to Broad and Linkhorn Bays, either 200 ft wide by 7 ft deep or 100 ft wide by 10 ft deep, will provide the desired tidal range in the upper reaches of Broad and Linkhorn Bays; (c) the entrance channel will be subject to some shoaling, largely confined to a relatively short length of the channel, unless the channel is protected by a jetty system; (d) a single jetty on the east side of the channel will be almost as effective as parallel jetties of equal length in preventing reshoaling of the channel; and (e) since it was not possible to determine the amount of shoaling of the entrance channel per unit of time, the channel should first be dredged and the rate of shoaling observed prior to construction of a protective jetty or jetties.

LYNNHAVEN BAY AND INLET, VIRGINIA

Model Investigation

PART I: INTRODUCTION

Location and Description of Prototype

1. Lynnhaven Inlet is located on the south shore of Chesapeake Bay 5 miles west of Cape Henry and 11 miles east of Norfolk, Va. The vicinity map, fig. 1, shows the geographical location of the inlet. The inlet provides the entrance to Lynnhaven Bay, which is divided into Eastern and Western Branches, and to Broad and Linkhorn Bays which lie to the east of Lynnhaven Bay and are connected thereto by Long Creek and a small canal (see fig. 2, page 5). The combined surface area of the bays is approximately 7 sq mi and the depths are relatively shallow, the maximum being about 7 or 8 ft at low tide.

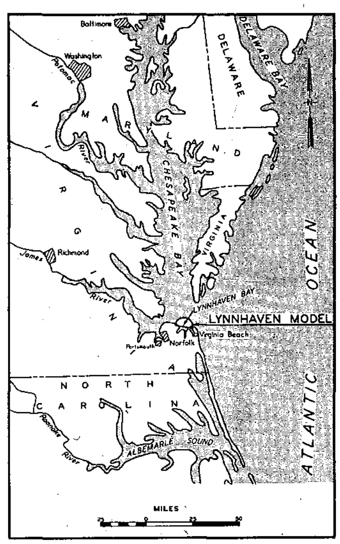

Fig. 1. Vicinity map

2. The tidal range at the entrance to Lynnhaven Inlet is approximately 3 ft for a spring tide. The range in Lynnhaven Bay is roughly equivalent to two-thirds of that at the entrance, or about 2 ft for a spring tide. In Broad and Linkhorn Bays, however, the range is only about 0.1 to 0.2 ft. The very small tidal range in these bays is caused by the limited and shallow channels of Long Creek and the canal which provide the only access for tidal flow.

3. Lynnhaven Inlet is crossed by two bridges, a state highway bridge and the Norfolk-Southern Railway bridge. Both structures are supported on pile bents, spaced approximately 10 ft apart, except for navigation openings about 31 ft wide in each bridge. Approach fills 750 ft long on the east side of the inlet and 250 ft on the west side were made during construction of the highway bridge. The east and west approaches to the railway bridge consist of pile-supported trestles.

4. Depths in Chesapeake Bay off-shore from the inlet entrance are relatively shallow for a distance of about 3000 ft, but increase from 6 ft to about 20 ft within the next 500 ft. There is no well-defined channel between the inlet entrance and the 6-ft contour of depth in Chesapeake Bay, and the controlling depth across this bar is about 3 ft at low tide.

Problems Involved

5. Two major problems exist at Lynnhaven Inlet: (a) the need for an adequate entrance channel through Lynnhaven Inlet and a mooring and turning basin in Lynnhaven Bay, connected by channels into Broad and Linkhorn Bays, for the safe and easy operation of commercial and pleasure craft; and (b) the need for a sufficient volume of tidal flow into and out of Lynnhaven, Broad, and Linkhorn Bays for the successful propagation of shellfish. Solution of the two problems must be closely coordinated in that the improvements for navigation must also be adequate to provide the tidal flow necessary to benefit the growth of shellfish. Those interests engaged in the cultivation of shellfish, in sport and commercial fishing, and in recreational boating have requested that navigation improvements be provided to develop a base of operations convenient to the

waters of Chesapeake Bay and the Atlantic Ocean with adequate channel and mooring facilities, and also that a readily accessible and adequate harbor of refuge for small craft be provided.

6. Local interests state that the existing shoals outside the inlet retard tidal flow through the inlet and in waters tributary thereto. They claim that 20 to 25 years ago the bottoms of these tributaries produced large crops of high-grade oysters and clams, and that while the bottom acreage now used for oyster and clam cultivation does not vary substantially from that formerly used, production has been reduced to a large extent. They state further that the waters of Broad and Linkhorn Bays have become polluted to such a degree that these areas can now be used only for the cultivation of seed oysters, and that the seed oysters have to be removed to beds in Lynnhaven Bay in their early stages of growth.

Types of Models Utilized

7. The problems discussed above can be divided into two major phases: (a) determination of the depths, widths, and locations of channels required to provide adequate tidal flow for shellfish production and sufficient channel depth to permit navigation by shallow draft boats; and (b) determination of whether or not the improved channel across the outer shoals would be subject to excessive reshoaling, and if so, a development of a system of jetties to prevent such shoaling and determination of the effects of the jetties on the beaches adjacent to the inlet. The first of these phases was investigated in a fixed-bed model reproducing a small portion of Chesapeake Bay and all of Lynnhaven Inlet, Lynnhaven Bay, Broad Bay, and Linkhorn Bay. The second phase involved use of a

movable-bed model reproducing a somewhat larger portion of Chesapeake Bay outside the inlet and a small portion of Lynnhaven Bay inside the inlet. Both of these models are described in part II.

PART II: THE MODELS

Fixed-bed Model

Description

8. The fixed-bed model (fig. 2), reproducing a portion of Chesapeake Bay outside Lynnhaven Inlet and all of the interior bay system, was

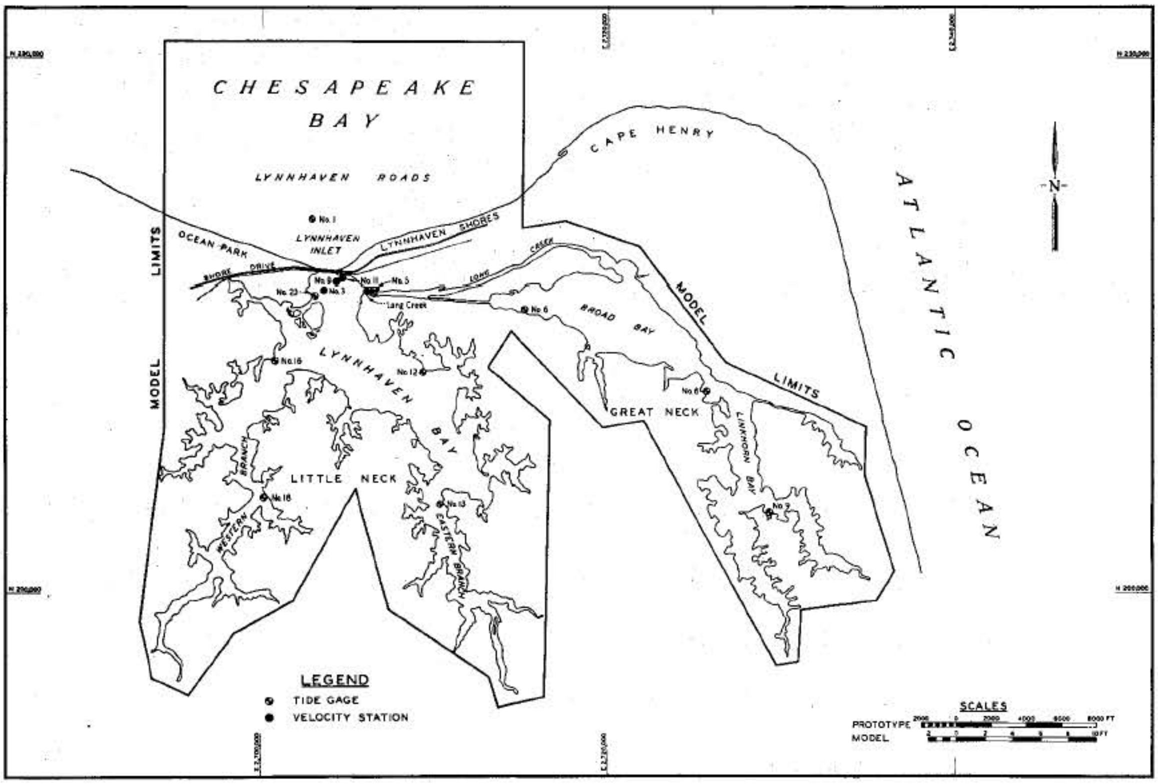

Fig. 2. Fixed-bed model

constructed of concrete to a horizontal scale of 1:800 and a vertical scale of 1:80. The railway and highway bridges across Lynnhaven Inlet were constructed to scale so that the effects of the structures on tidal flow would be reproduced accurately. A general view of the fixed-bed model is shown in fig. 3.

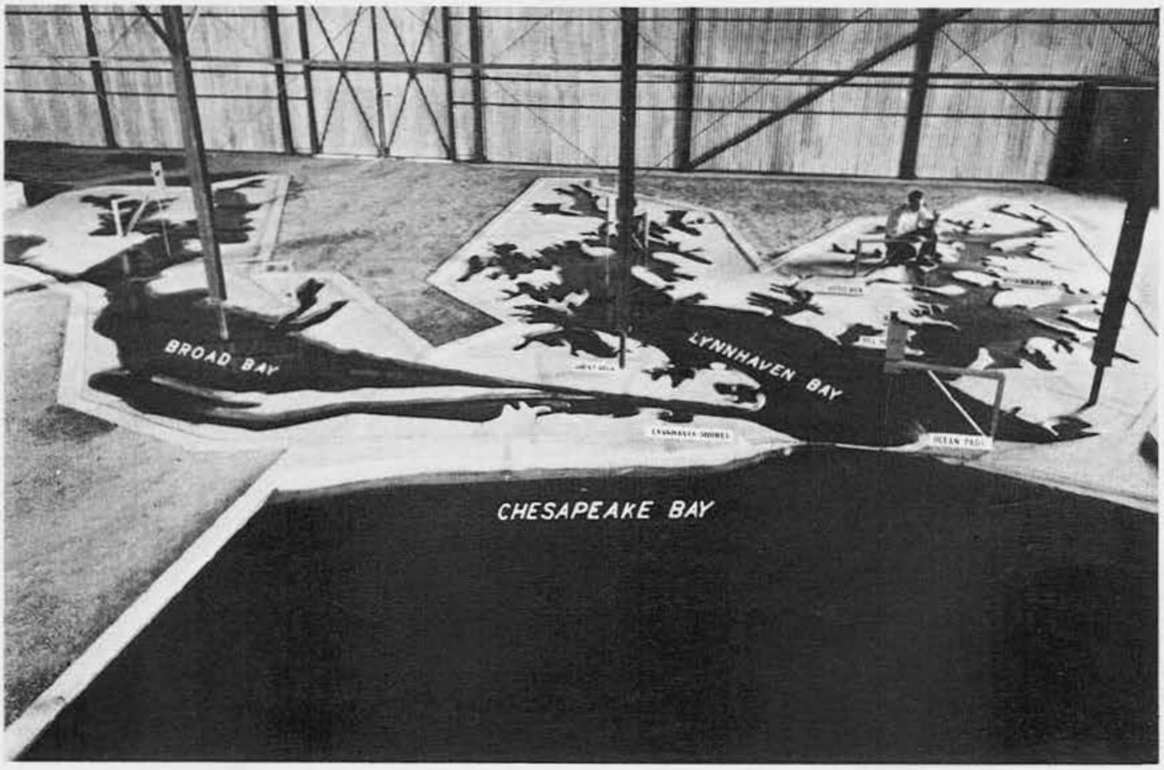

Fig. 3

Appurtenances

9. Tides and tidal currents were reproduced in the fixed-bed model by a single tide-control mechanism located in the Chesapeake Bay portion of the model. This mechanism, through an arrangement of pumps, valves, and electrical relays, controlled the rate of flow into and out of the model as required to reproduce properly the rise and fall of the tide therein.*

Movable-bed Model

Description

10. The movable-bed model (fig. 4) reproduced a somewhat larger

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* This apparatus is described in detail in paragraphs 16-18 of Waterways Experiment Station Technical Memorandum No. 2-244, "Plans for the Improvement of the St. Johns River, Jacksonville to the Atlantic Ocean; Model Investigation."

portion of Chesapeake Bay outside Lynnhaven Inlet and the inlet to a point approximately 4000 ft south of the railway bridge. The movable-bed portion of the model was roughly rectangular in shape and included the Chesapeake Bay shore lines for distances of 10,000 ft east and west of the inlet, the offshore area of Chesapeake Bay to about the 25-ft contour of depth, and the inlet proper to a point about 3000 ft south of the

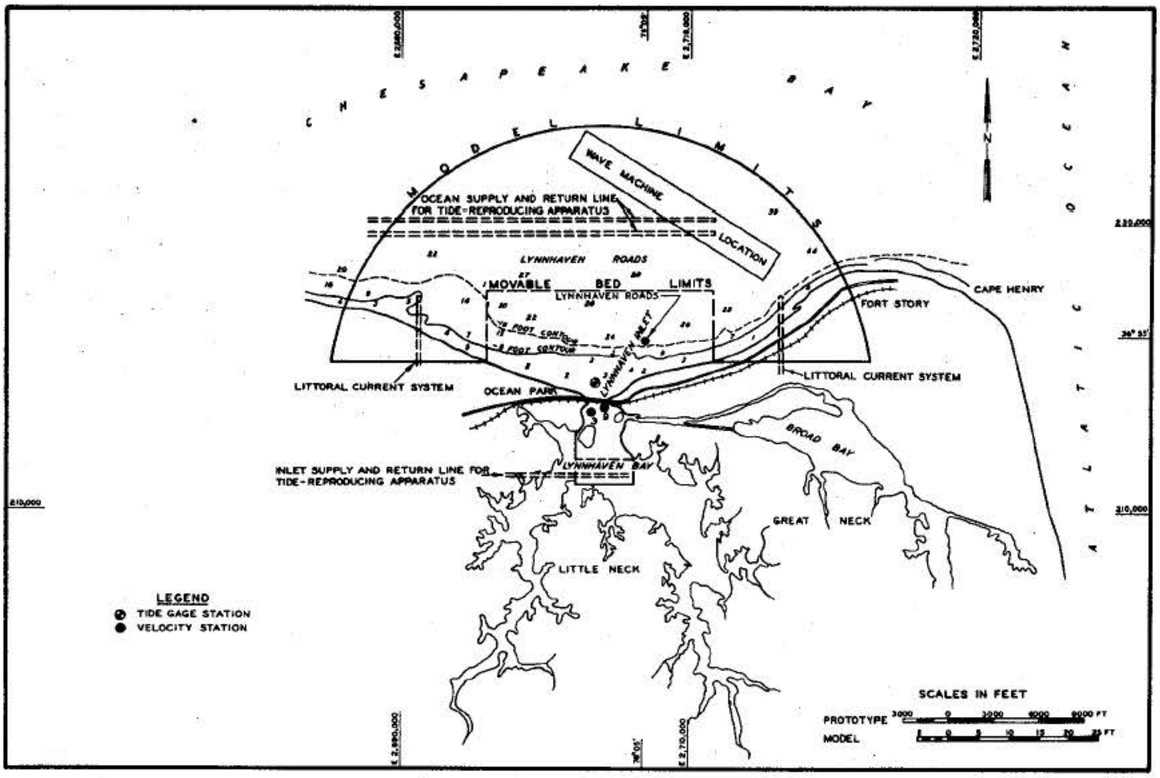


Fig. 4. Movable-bed model

railway bridge. A general view of the movable-bed model is shown in fig. 5. The linear scales of the movable-bed model were 1:400 horizontally and 1:80 vertically.

11. The movable-bed portion of the model was molded of sand having a median grain diameter of about 0.2 mm. The remainder of the model was molded of concrete to provide space for the wave machine and the inflow

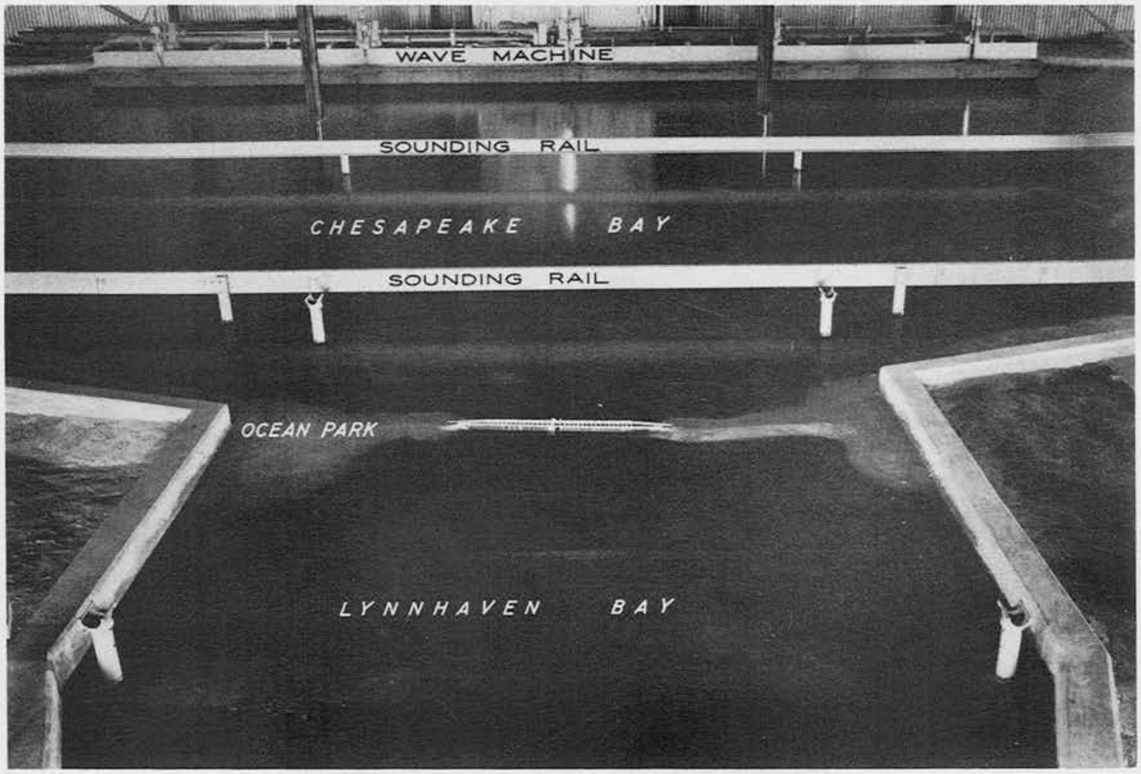


Fig. 5

and outflow lines for the tide-control mechanism. Sheet-metal templates, mounted on graded rails, were used to mold the movable-bed portion of the model at the beginning of each test.

Appurtenances

12. Tide-control mechanism. Tides in the movable-bed model were reproduced by two tide-control mechanisms, one located in the Chesapeake Bay portion of the model and the other located at the cutoff point in Lynnhaven Inlet. The mechanism located in the Chesapeake Bay portion of the model reproduced the rise and fall of tide therein, while the mechanism located in Lynnhaven Inlet reproduced tidal discharges and velocities through the inlet. The second mechanism reproduced accurately the effects of the bay tidal prism, which was not incorporated in the movable-bed model.

13. Wave machine. Waves were reproduced in the movable-bed model by means of a 40-ft-long plunger-type machine. The wave machine was mounted on rollers to permit easy movement from place to place. The speed and submergence of the plunger were adjustable to permit reproduction of waves of the proper height and period.

14. Littoral current apparatus. Tidal currents in Chesapeake Bay accelerate and retard the alongshore or littoral currents throughout the area reproduced in the movable-bed model. The prevailing direction of the littoral currents is from east to west, caused by waves breaking obliquely on the beach. Reproduction of the littoral currents was considered necessary since it was believed that their action would be a contributing factor to possible reshoaling of the improved channel. The apparatus used to reproduce littoral currents consisted of bays constructed at each end of the movable-bed section (fig. 4), connected by a continuous pipe in which was installed a propeller-type reversible pump. A motorized, rising stem valve was installed in the pipe to control the rate of flow therein. With the pump operating and the valve open, water was removed from the model at one end of the movable-bed section and introduced at the opposite end, thus setting up a current from one end of the movable-bed section to the other. The cycle of operation of the mechanized valve was controlled by a cam, operated in accordance with the model time scale, and trip switches were installed on the cam to start, stop, and reverse the pump motor at the proper times. The control cam started the pump motor in the proper direction, gradually opened and closed the control valve to reproduce the proper cycle of current velocities, and stopped the pump motor at the subsequent time

of slack water in Chesapeake Bay.

15. Sounding carriage and scale. The movable-bed portion of the model was sounded at frequent intervals by means of a movable sounding carriage, mounted on rails, and a sliding sounding scale. One side of the sounding carriage was graduated so that distances from a base line could be determined accurately and quickly. With the sounding carriage located on a sounding range, the elevations of the bed were determined by a sliding sounding stick graduated to read to the nearest foot of depth. A metal shoe on the bottom of the sounding stick prevented the stick from penetrating the sand bed.

General Procedure of the Model Study

16. Following construction of the fixed-bed and movable-bed models, the testing program was conducted in five general phases: (a) hydraulic adjustment and verification of both models for existing channel conditions; (b) bed-movement adjustment and verification of the movable-bed model for existing conditions; (c) tests of plans in the fixed-bed model; (d) a test in the movable-bed model of the most promising channel improvement plan (developed from tests in the fixed-bed model) without jetties; and (e) tests in the movable-bed model of the most promising channel improvement plan with various jetty arrangements. The above phases of testing are described in detail in subsequent parts of this report.

PART III: VERIFICATION OF THE MODELS

Fixed-bed Model

Procedure

17. Verification of the fixed-bed model consisted of adjusting the tide-control mechanism to reproduce accurately the observed prototype tide in Chesapeake Bay and then adjusting the roughness of the model bed until tidal heights and current velocities throughout the interior bay system were reproduced to scale. Prototype tidal data were available for 10 stations and velocity data for four stations in the area covered by the model (fig. 2, page 5). Tidal data obtained at station 1 in Chesapeake Bay were used for adjustment of the tide-control mechanism. Prototype data at all stations were obtained simultaneously so that no corrections of field observations were required.

Results

18. The accuracy with which prototype tidal heights and times were reproduced in the model is shown on plates 1 through 3. It will be noted that tidal phenomena at station 1, the control station used for adjustment of the tide-control mechanism, were duplicated almost exactly (plate 1). Tidal heights at other stations throughout the model, with the single exception of low water at station 5, were within about 0.2 ft to 0.3 ft of the corresponding tidal elevations in the prototype. The elevation of low water at station 5 was approximately 0.4 ft higher in the prototype than in the model. It is pointed out, however, that the prototype elevation of low water at station 5 was about 0.35 ft higher than that at station 23, which is located just across the inlet from station 5.

The low-water elevation at station 5 might be affected to some extent by ebb flow from Long Creek; however, it is believed that some other factor, possibly wind blowing across the inlet at the time of the prototype observations, caused an unusually high low water at station 5.

19. Current velocity observations made in the model at four stations in Lynnhaven Inlet and Long Creek (see fig. 2) checked the corresponding prototype observations very closely (plate 4). Model velocities were within about 0.5 ft per sec of corresponding prototype velocities at all observation stations.

Discussion of results

20. The degree of accuracy with which prototype tidal heights and current velocities were reproduced in the fixed-bed model was considered sufficient for the purposes of the study. Because of the high degree of similitude attained, it was considered that the model would indicate properly changes from existing conditions as affected by the proposed improvement plans to be tested.

Movable-bed Model

Procedure

21. Verification of the movable-bed model consisted of the following two phases: (a) hydraulic adjustment, which involved adjustment of the two tide-control mechanisms and the littoral current apparatus so that tides and currents were reproduced accurately throughout the model; and (b) adjustment of bed movement, which consisted of adjusting the model time scale and hydraulic elements (current and wave action) in such manner that the movement of bed material in the model reproduced as

closely as possible that of the prototype.

Hydraulic adjustment

22. The tide-control mechanism located in the Chesapeake Bay portion of the model was adjusted to reproduce the prototype tide at station 1. The inlet tide-control mechanism (located at the model cutoff point south of the railway bridge) was then adjusted so that prototype current velocities at stations 3 and 9 in Lynnhaven Inlet were reproduced to scale. A mean velocity curve was computed for the Lynnhaven Roads station (fig. 4, page 7), using the 1946 Atlantic Coast Current Tables prepared and published by the U. S. Coast and Geodetic Survey. The littoral current apparatus was adjusted to reproduce this computed velocity curve.

Results of hydraulic adjustment

23. The accuracy with which the model reproduced tidal phenomena in Chesapeake Bay, current velocities at stations 3 and 9, and tidal currents in Chesapeake Bay at Lynnhaven Roads is shown on plate 5. It was considered that the model reproduction of all pertinent hydraulic elements was sufficiently accurate.

Basis of bed-movement adjustment

24. The usual procedure followed in adjusting bed movement in a movable-bed model is to select a verification period, usually the period between two complete hydrographic surveys of the area under investigation, and, starting with the movable bed molded to the earlier survey, adjust the hydraulic forces in such manner that the conditions of the bed after a certain period of operation are similar to those shown by the later prototype survey. In this manner, trends of bed movement in the model can be adjusted to follow those of the prototype, and the time required in the

model to effect the hydrographic changes which occurred in the period between prototype surveys establishes the model time scale for bed movement.

25. It was intended that the above-outlined procedure would be followed during adjustment of the subject model. However, a study of all existing surveys of the problem area, made prior to construction of the model, revealed that hydrographic data required for adjustment of bed movement were not available. It was therefore decided that a survey program would be established to obtain all necessary data, and the first comprehensive survey under this program was made by the Norfolk District in January 1947. The program as outlined called for a second comprehensive survey to be made about one year later, or in January 1948, followed by other surveys if required.

26. The survey of January 1947 was used as a basis for constructing the model. In December 1947, the Norfolk District started, as a check of possible changes in conditions during the 11-month period, the second hydrographic survey called for under the program, and it was noted immediately that no significant changes in bed configurations had occurred since the survey of January 1947. The new survey was therefore discontinued, it being recognized that the period between the two surveys could not be used as a basis for adjusting bed movement in the model.

27. All available hydrographic surveys of Lynnhaven Inlet, covering the period 1891-1947, were examined and analyzed. It was found that no major changes in bed configuration had occurred in the 56-year period covered by these surveys. It was therefore decided that the obtaining of additional hydrographic surveys of the area would be a waste of time and funds, since it appeared that bed configurations throughout the area had

reached a state of stability.

28. The results of an investigation of beach erosion at Willoughby Spit, located on the south shore of Chesapeake Bay about 12 miles west of Lynnhaven Inlet, indicated that the predominant movement of sand along that portion of the south shore of Chesapeake Bay is from east to west. Data obtained at Willoughby Spit were supplemented by the fact that Cape Henry, located to the east of Lynnhaven Inlet, had shown a tendency to erode during the same period that Willoughby Spit had shown accretion, thus indicating that material eroded from Cape Henry passed through the Lynnhaven Inlet area before being finally deposited on Willoughby Spit. Conditions at Little Creek entrance, located about 5 miles west of Lynnhaven Inlet, also indicated that the predominant movement of material is from east to west, there having been accretion to the east and erosion to the west of Little Creek entrance since jetties were constructed there.

29. With the above considerations in mind, it was decided that the model should be so adjusted as to produce a continuous movement of material from east to west throughout the movable-bed section, and at the same time maintain a fairly stable condition throughout the problem area, as indicated by prototype surveys. It was recognized, of course, that the absence of quantitative data for adjustment of bed movement would preclude the obtaining of quantitative data on bed movement during model tests of proposed improvement plans; however, since the obtaining of quantitative bed-movement data did not appear possible, no other method of adjustment could be followed.

Description of bed-movement adjustment

30. A series of trial tests was made in the model to determine the

optimum wave height and length, direction of wave approach, and manner of feeding sand to the easterly end of the movable bed to accomplish the conditions established as adjustment criteria. A description of the manner in which the model was operated during the final bed-movement adjustment test is contained in the following paragraphs.

31. Tides and current velocities. Tides and current velocities reproduced in the model were in accordance with data shown on plate 5.

32. Wave height, length, and direction of approach. The wave selected for reproduction in the model (on the basis of trial adjustment tests) was approximately 5 ft high and 160 ft long (using the vertical scale of 1:80 for both height and length of wave). It had been determined from trial tests that a wave of these dimensions would cause movement of the model bed material in depths of 15-18 ft below low water. The direction of approach of the waves (position of the wave machine) is shown on fig. 4, page 7; however, changes in bottom configurations caused considerable bending of the waves so that they struck the beach almost perpendicularly. During certain of the trial adjustment tests the position of the wave machine was shifted intermittently to reproduce waves from different directions; however, it was found that waves from the position shown on fig. 4 produced a generally westerly movement of the model bed material. It was decided to reproduce waves from this position only, since it was considered probable that most waves sufficiently large to cause appreciable bed movement in the prototype approach Lynnhaven Inlet from this general direction (from the entrance of Chesapeake Bay into the ocean).

33. Introduction and removal of bed material. It was necessary to

introduce sand at the easterly end of the movable-bed section and remove that passing from the westerly end, since the movable-bed portion of the model extended only about two miles to the east and west of Lynnhaven Inlet. Sand introduced at the easterly end represented littoral drift approaching Lynnhaven Inlet from Cape Henry, and sand removed from the westerly end represented that which would pass on toward Little River Inlet and Willoughby Spit. A narrow strip of the concrete bed of the model, adjacent to the movable-bed section, was kept covered lightly with sand throughout the course of the test. Additional material was added to keep the area covered as the waves moved sand away, since the volume of littoral drift in the prototype was not known. The sand moving out of the westerly end of the movable-bed section was collected and measured as an index to the volume of littoral drift in motion.

34. Duration of test. The test was started with the movable-bed section molded to the prototype survey of January 1947, and was continued through 12 complete cycles of tides, waves, and currents (about 3.5 hours actual time). Observations of bed movement during the course of the test indicated that certain minor changes in bed configurations occurred during the first 8 cycles of operation, following which the conditions of the bed remained relatively unchanged during the remainder of the test. The test was discontinued at the end of 12 cycles of operation, because the bed had reached an apparently stable condition; however, subsequent tests including proposed improvement plans were continued for a longer period of time to insure that the bed had reached a stable condition.

Résults of bed-movement adjustment

35. The condition of the movable bed at the beginning and end of

the test (1947 prototype survey) is shown on plates 6 and 7, respectively. Plate 8 shows the changes in bed conditions which occurred during the course of the tests. It will be noted that the maximum changes in bed conditions during the test were in the vicinity of the inlet channel; conditions throughout the remainder of the movable-bed section remained relatively unchanged. The 6-ft and 12-ft contours of depth moved slightly shoreward immediately offshore from the inlet, and existing bar formations to the east and west of the inlet channel were built up slightly, the bar to the east being built up to a greater extent that that to the west. The condition of the movable bed as a whole was not changed appreciably during the test.

36. A total of 61,600 cu yd of material moved out of the west end of the movable-bed section during the test, indicating that the average volume of westerly littoral drift in the model was slightly greater than 5,000 cu yd per tidal cycle. The amount of material moved into the easterly end of the movable-bed section was approximately the same as that moved out of the westerly end. The above amounts of material indicate that approximately 5,000 cu yd of material per tidal cycle moved through the problem area in the model, since the areas of scour and fill shown on plate 8 approximately balance, there being but little gain or loss of material in the movable-bed section.

Discussion of results of bed-movement adjustment

37. The Waterways Experiment Station is not aware of any area, having physical characteristics similar to those of Lynnhaven Inlet, for which the rate of littoral drift has been determined accurately. At Absecon Inlet, New Jersey, and Santa Barbara Harbor, California, rates

of littoral drift have been measured and computed. The average rate of drift at both localities is stated to be in the order of 1,000 cu yd per day, or approximately 500 cu yd per tidal cycle. In both of these areas, however, the length of beach to windward of the point of measurement is considerably greater than that at Lynnhaven Inlet; also, both areas are subject to direct attack by ocean waves, while the Lynnhaven Inlet area is protected to some extent by the headlands at Cape Henry and Cape Charles. It appears probable, therefore, that the average rate of littoral drift at Lynnhaven Inlet is considerably less than 500 cu yd per tidal cycle.

38. It is considered that the model bed-movement adjustment was as accurate as could be obtained on the basis of available knowledge of prototype volume of littoral drift passing through the area covered by the movable-bed section. The volume of littoral drift in the model (5,000 cu yd per tidal cycle) probably was considerably greater than the amount being moved in the prototype. It appears, therefore, that the results of model tests of shoaling in the outer channel should be well on the conservative side.

PART IV: NARRATIVE OF TESTS, FIXED-BED MODEL

Base Test

39. The initial test made in the model following completion of adjustment and verification was a base test, or test of existing prototype conditions. The purpose of this test was to obtain measurements of tidal heights and current velocities under existing conditions which, when compared to measurements obtained at the same stations during subsequent tests of improvement plans, would indicate the changes from existing conditions effected by each plan tested.

40. With the existing channels installed in the model, measurements of tidal heights were obtained at stations 5, 6, 8, 9, 12, 13, 16, 18, and 23, and current velocity measurements were obtained at stations 3, 9, 11, and in Long Creek. The locations of tide and velocity stations are shown on fig. 2, page 5. Tide and velocity data obtained during the base test are presented on all plates and tables which present comparable data obtained at the same stations during subsequent tests of improvement plans. Thus, the effects on tidal heights and current velocities of each plan tested may be determined by noting changes from existing conditions which were effected by its installation in the model.

Tests of Improvement Plans

Plan 1

41. Plan 1 (fig. 6) consisted of the following elements:

a. Riprap jetties, having a top elevation of 6.0 ft above low water, extending from the 18-ft contour of depth in Chesapeake Bay to the shore adjacent to each end of the highway bridge across Lynnhaven Inlet.

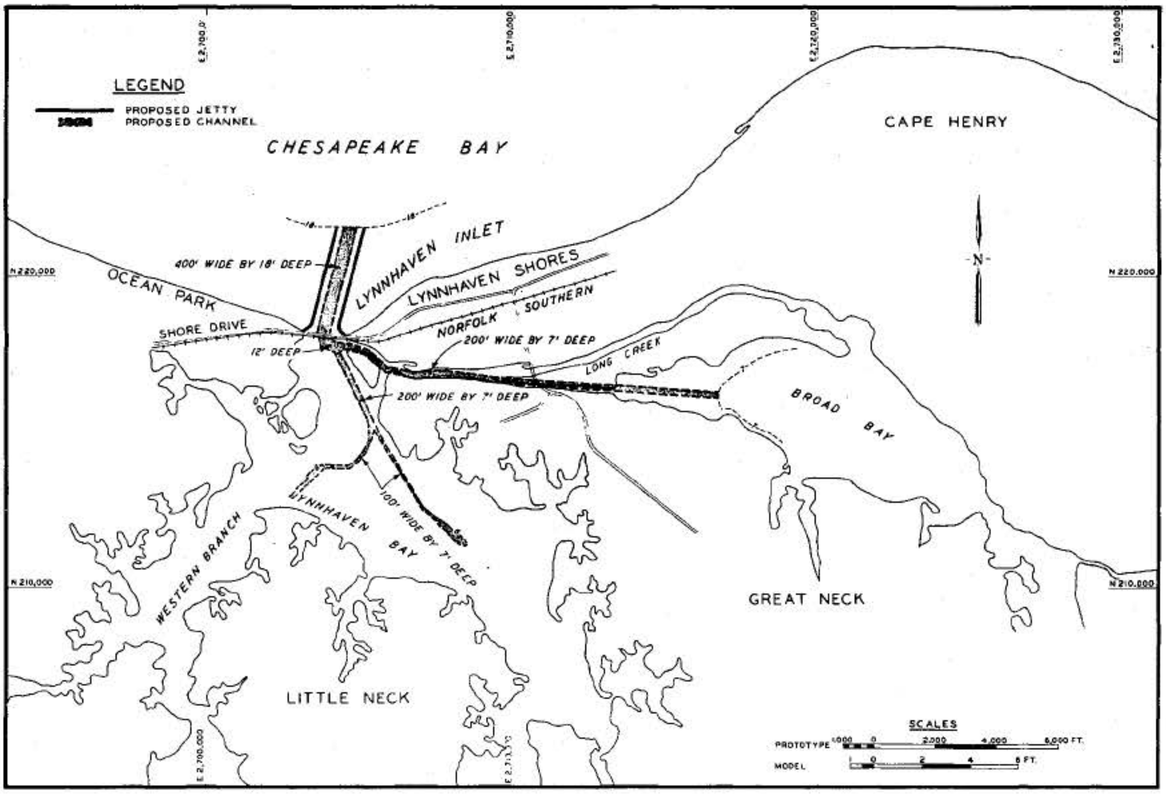


Fig. 6. Elements of plan 1

b. A channel between the jetties, 400 ft wide and 18 ft deep, beginning at the 18-ft contour of depth in Chesapeake Bay and extending to the highway bridge across the inlet.

c. A channel 12 ft deep and of variable width extending from the highway bridge to the entrance of Long Creek into Lynnhaven Bay.

d. Two 200-ft-wide by 7-ft-deep channels beginning at the terminus of the 12-ft-deep channel. One channel extended up Lynnhaven Bay to the junction of the eastern and western branches, where it divided into two 100-ft-wide channels, one following each branch, to the 6-ft contour of depth. The other 200-ft channel passed through a portion of Long Creek, the canal, and into Broad Bay to the 7-ft contour of depth.

42. The effects of plan 1 on tidal heights and current velocities are shown on plates 9-12 and in tables 1-3. The plan increased the range of tide in Broad Bay (station 6) from 0.2 ft to about 1.0 ft, and increased the range in Linkhorn Bay (station 9) from 0.2 ft to about 0.9 ft.

The tidal range in Long Creek (station 5) was reduced from about 2.3 ft to about 1.8 ft, owing to the large increase in flow through Long Creek into and out of Broad and Linkhorn Bays. In Lynnhaven Bay proper (station 12) the plan had no measurable effect on the tidal range; however, in the eastern and western branches (stations 13 and 18) the range was increased slightly and the planes of high and low water were lowered slightly. At station 23, just inside the railroad bridge, the tidal range was increased by about 0.1 ft by a lowering of the low water plane. Current velocities at stations 3 and 9 were not affected appreciably; however, at station 11 and in Long Creek, both flood and ebb velocities were increased considerably.

Plan 2

43. Plan 2 (fig. 7) was the same as plan 1 except that the jetties along the outer portion of the channel were omitted.

44. The effects of plan 2 on tidal heights and current velocities are shown on plates 13-16 and in tables 1-3. The plan had approximately the same effects on tidal heights and current velocities as did plan 1, indicating that the jetties of plan 1 had but little effect on hydraulic conditions in the interior bay system.

Plan 3

45. Plan 3 (fig. 8) was similar to plan 1 with the following exceptions:

a. The jetties of plan 3 ended at the 12-ft contour of depth in Chesapeake Bay instead of the 18-ft contour.

b. The 400-ft-wide channel between the jetties was 12 ft deep instead of 18 ft deep.

c. The 7-ft-deep channel from Lynnhaven Bay to Broad Bay was 100 ft wide instead of 200 ft wide.

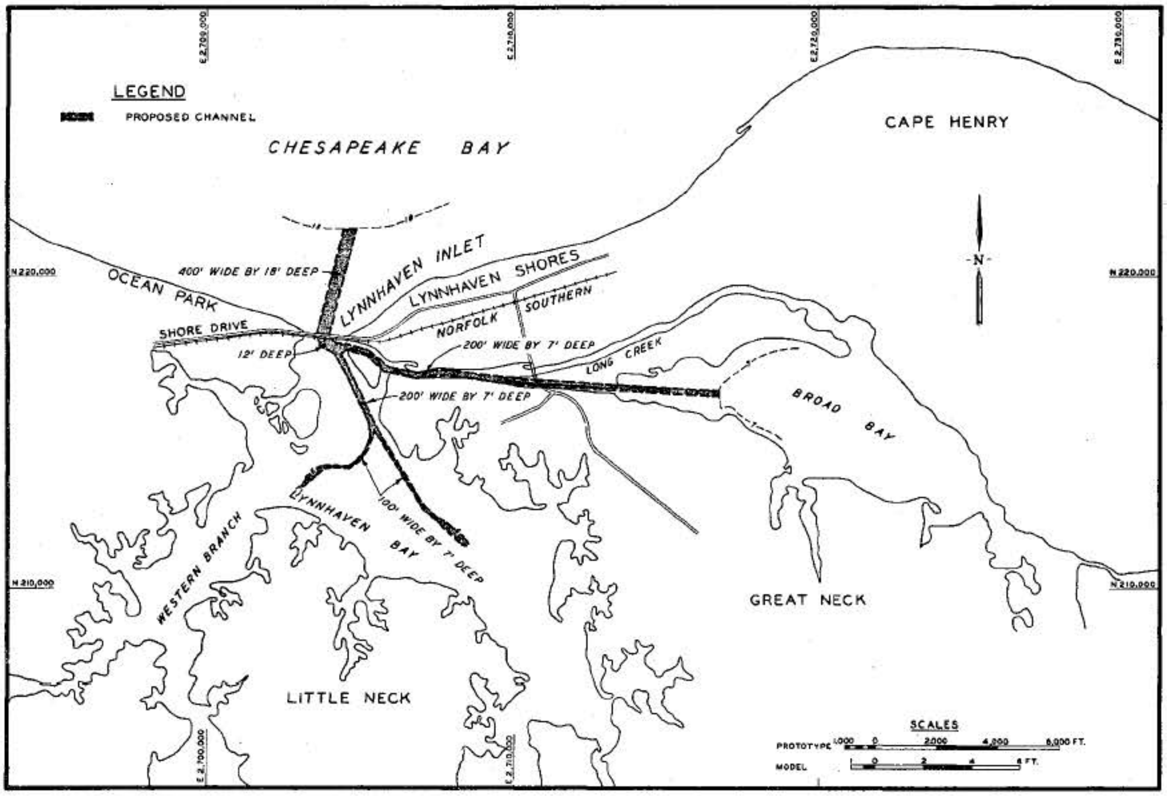


Fig. 7 Elements of plan 2

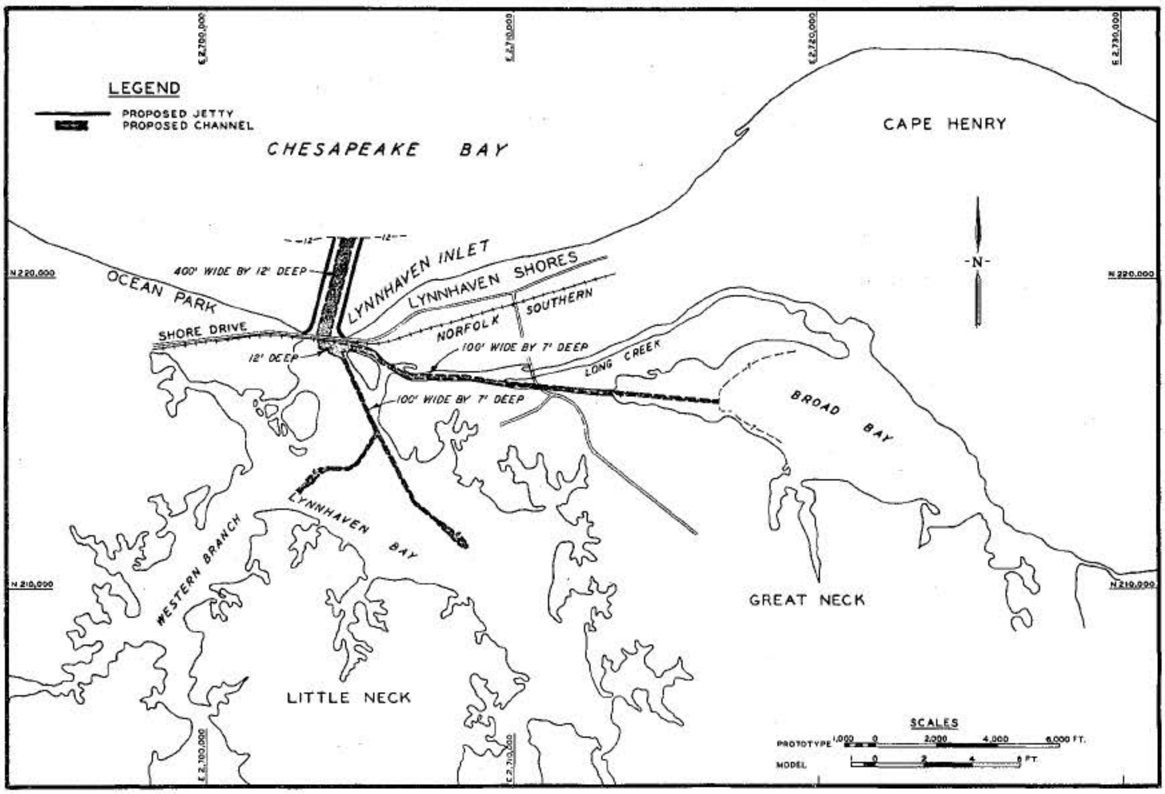


Fig. 8. Elements of plan 3

46. The effects of plan 3 on tidal heights and current velocities are shown on plates 17-20 and in tables 1-3. The plan increased the tidal range in Broad and Linkhorn Bays from about 0.2 ft to about 0.5 ft (stations 6, 8, and 9). In Long Creek (station 5) the tidal range was reduced from about 2.3 ft to about 2.0 ft. There was no appreciable change in the tidal ranges in Lynnhaven Bay proper and the eastern and western branches (stations 12, 13, 16, and 18); however, the planes of high and low water were lowered slightly, especially in the western branch. There was little change in current velocities at stations 3 and 9; however, velocities were increased appreciably at station 11 and in Long Creek.

Plan 4

47. Plan 4 (fig. 9) was identical to plan 3 with the one exception that the jetties were omitted.

48. Plan 4 had approximately the same effects on tidal heights and current velocities throughout the model (see plates 21-24 and tables 1-3) as did plan 3, indicating that the jetties of plan 3 had no appreciable effects on hydraulic conditions throughout the interior bay system.

Plan 5

49. Plan 5 (fig. 10) consisted of the following elements:

a. The 400-ft-wide by 12-ft-deep outer channel of plan 4 (without jetties), and the 100-ft-wide by 7-ft-deep channels into the eastern and western branches of Lynnhaven Bay.

b. A 12-ft-deep mooring basin just inside the railroad bridge.

c. An 80-ft-wide navigation opening through the bridges, located on the center line of the dredged outer channel.

d. The western entrance to the Lynnhaven Bay-Broad Bay channel

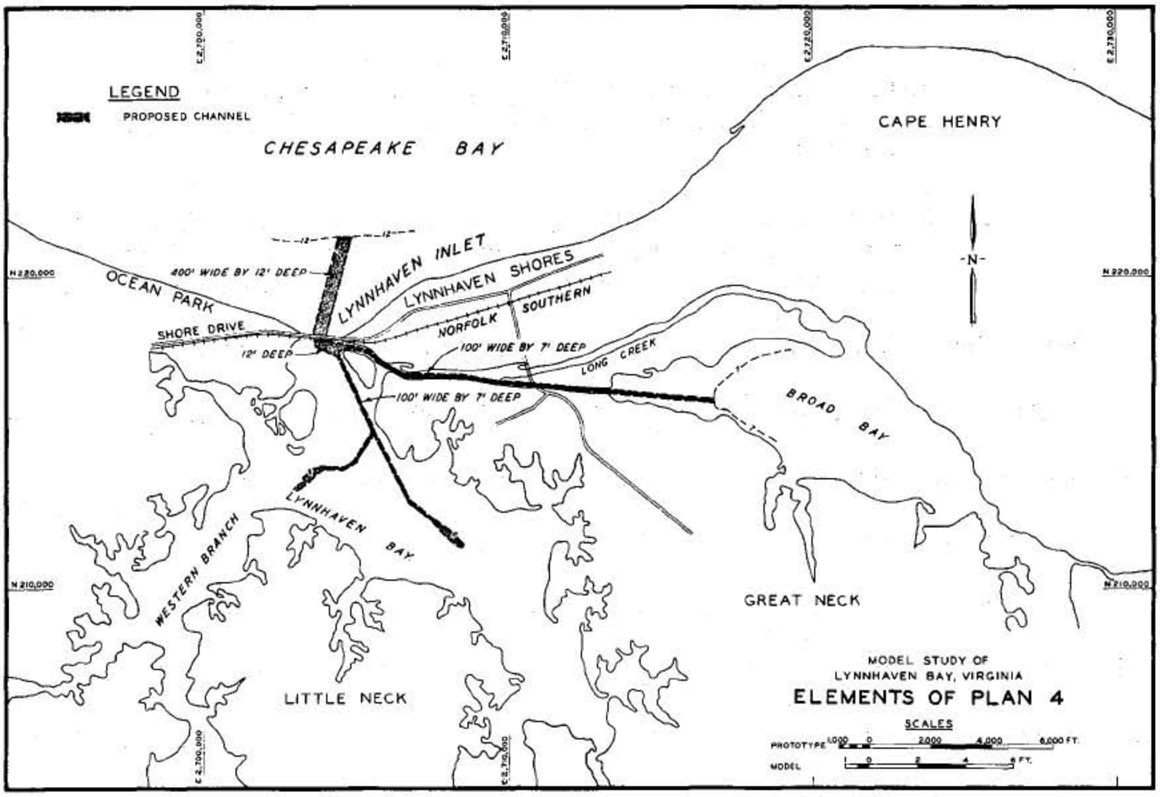


Fig. 9. Elements of plan 4

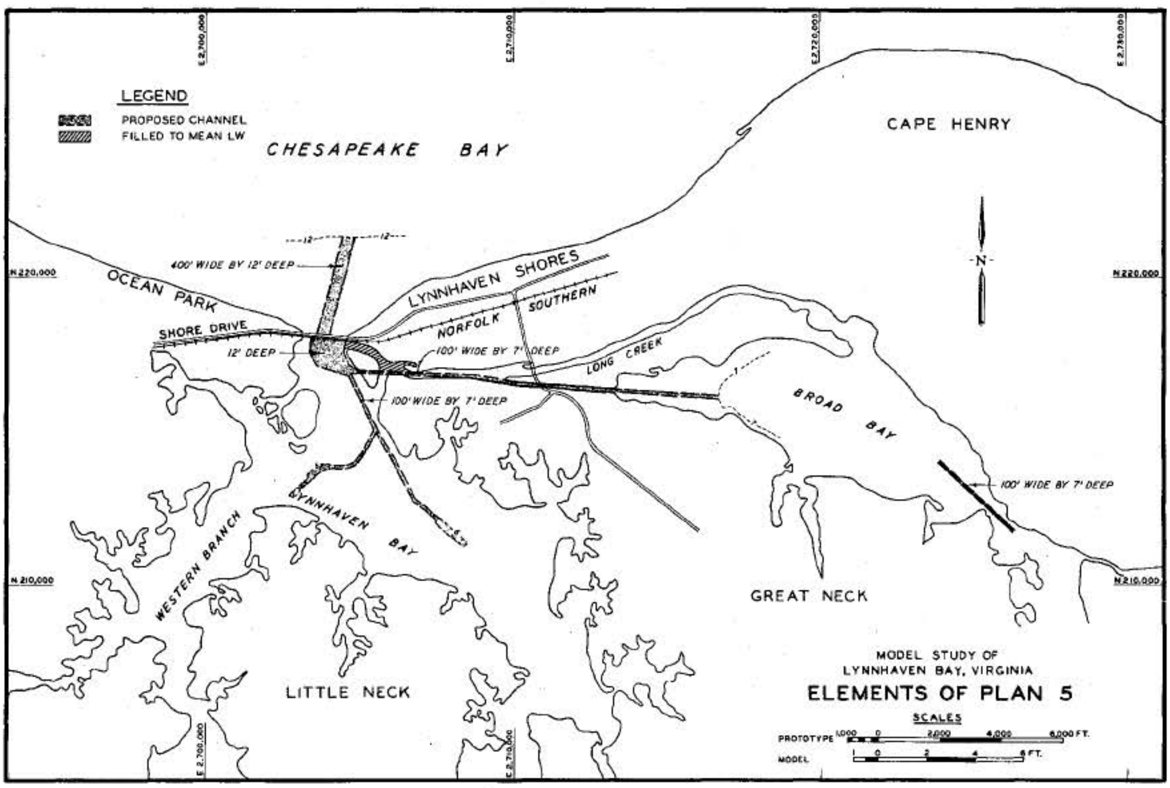


Fig. 10. Elements of plan 5

relocated as shown on fig. 10, and the abandoned portion of this channel filled to elevation 0.0 LW, Norfolk District Datum.

e. A channel 100 ft wide by 7 ft deep connecting Lynnhaven Bay with Broad Bay, and a channel of the same width and depth through the narrows from Broad Bay to Linkhorn Bay.

50. The effects of plan 5 on tidal heights and current velocities are shown on plates 25-28 and in tables 1-3. The plan had about the same effects on tidal heights and current velocities as did plans 3 and 4; however, current directions in and adjacent to the western end of the Lynnhaven Bay-Broad Bay channel were improved appreciably by realigning this channel. There was no indication of crosscurrents that might be hazardous to navigation. The mooring basin appeared to have no noteworthy effect on hydraulic conditions in the inlet or bays.

Plan 6

51. Plan 6 (fig. 11) was the same as plan 5 except that the 100-ft-wide channels into Broad and Linkhorn Bays were widened to 150 ft.

52. The effects of plan 6 on tidal heights and current velocities are shown on plates 29-32 and in tables 1-3. This plan increased the tidal range in Broad and Linkhorn Bays from 0.2 ft to about 0.65 ft. In all other respects the effects of plan 6 were similar to those of plan 5.

Plan 7

53. Plan 7 (fig. 12) was the same as plan 5 except that the channels into Broad and Linkhorn Bays were 200 ft wide instead of 100 ft wide.

54. The effects of plan 7 on tidal heights and current velocities (see plates 33-36 and tables 1-3) were to increase the tidal range in Broad and Linkhorn Bays from 0.2 ft to about 0.9 ft. Throughout the remainder of the interior bay system, the effects of plan 7 were about the

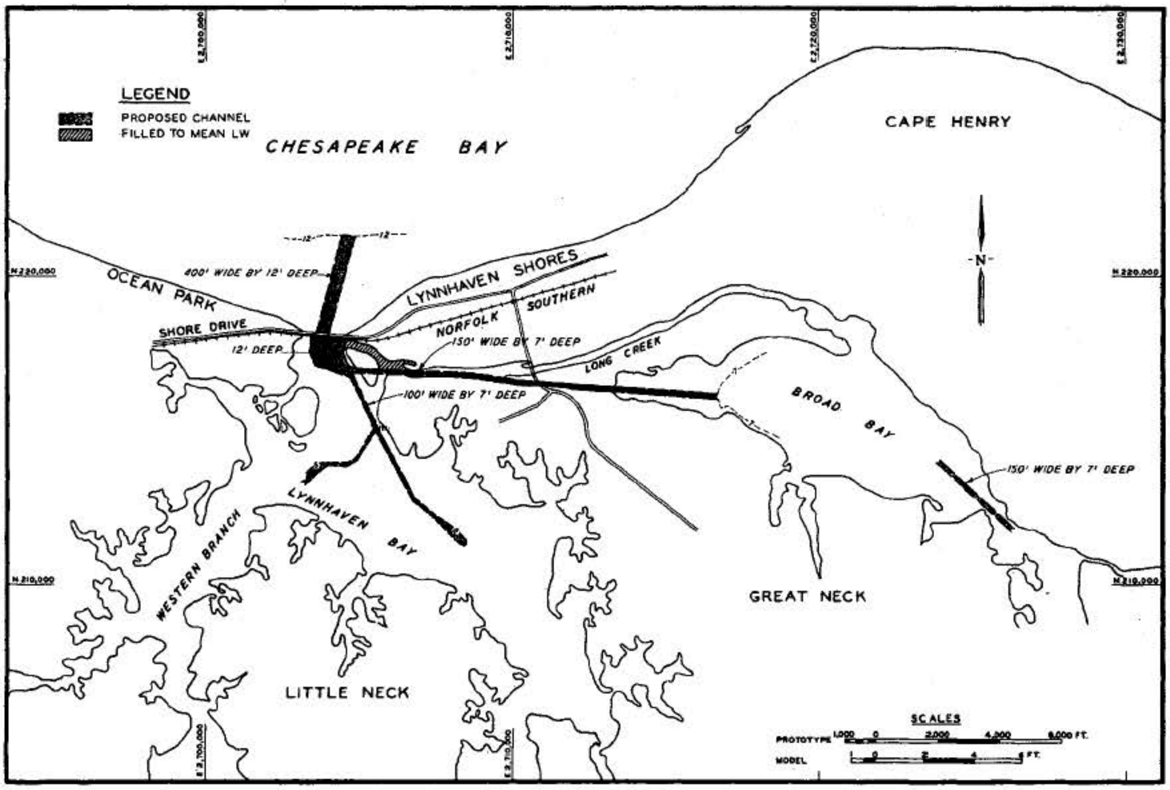


Fig. 11. Elements of plan 6

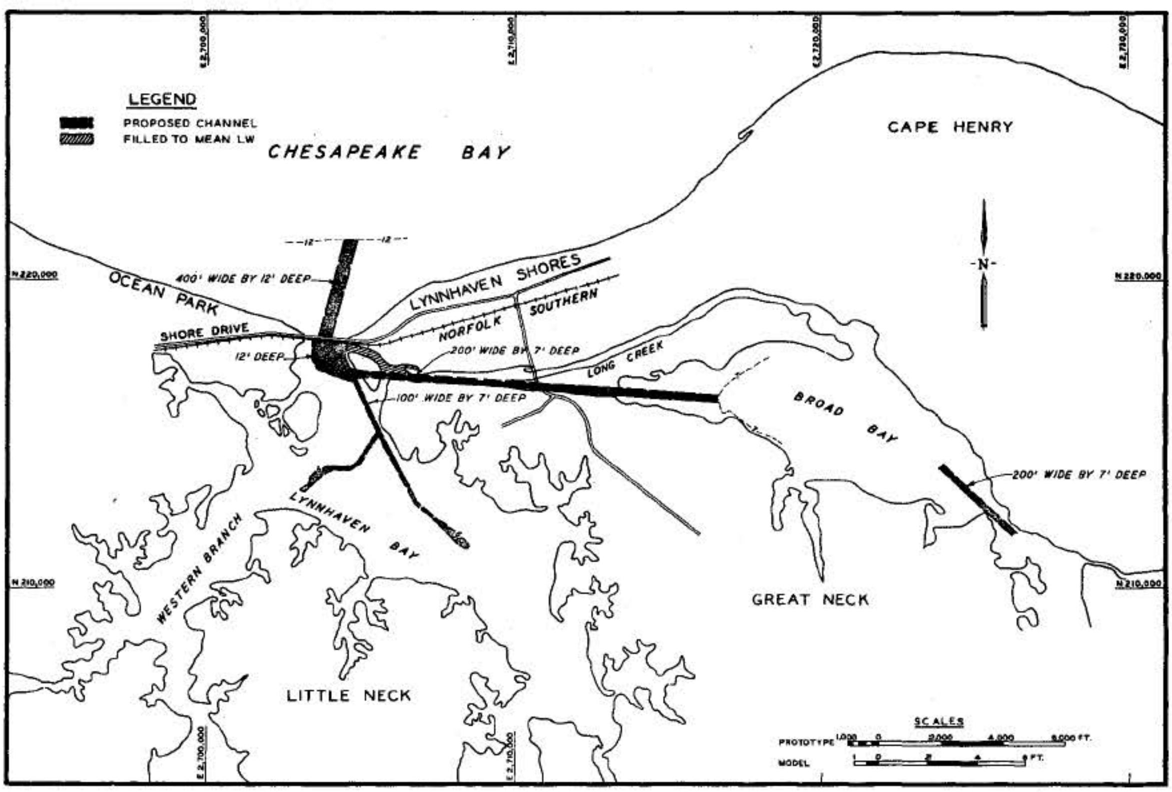


Fig. 12. Elements of plan 7

same as for plan 5.

Plan 8

55. Plan 8 (fig. 13) was the same as plan 5 except that the 100-ft-wide channel between Lynnhaven Bay and Broad Bay was 10 ft deep instead of 7 ft deep.

56. The effects of plan 8 on tidal heights and current velocities are shown on plates 37-40 and in tables 1-3. The tidal range in Broad and Linkhorn Bays was increased from 0.2 ft to about 1.0 ft. Tidal ranges throughout the remainder of the interior bay system, and current velocities in the inlet and in Long Creek, were about the same as for plan 5.

Plans 9, 10, and 11

57. Plans 9, 10, and 11 (figs. 14, 15, and 16) were made to determine the effects of the artificial fill, placed at each end of the highway bridge at the time of its construction, on flow into and out of the inlet. The fill extends into the inlet for a distance of about 750 ft on the east side and about 250 ft on the west side. Plans 9, 10, and 11 each incorporated the outer and interior channels of plan 7 described in paragraph 53. Plan 9 called for removal of one-third (250 ft) of the fill on the east side of the inlet. Plan 10 called for removal of two-thirds (500 ft) of the fill on the east side of the inlet, and one-half (125 ft) of the fill on the west side of the inlet. Plan 11 called for removal of the entire 750-ft fill on the east side of the inlet, and the entire 250-ft fill on the west side.

58. The effects of plans 9, 10, and 11 on tidal heights and current velocities are shown on plates 41-44, 45-48, and 49-52 respectively, and in tables 1-3. The results of the test of plan 9 indicate that removal

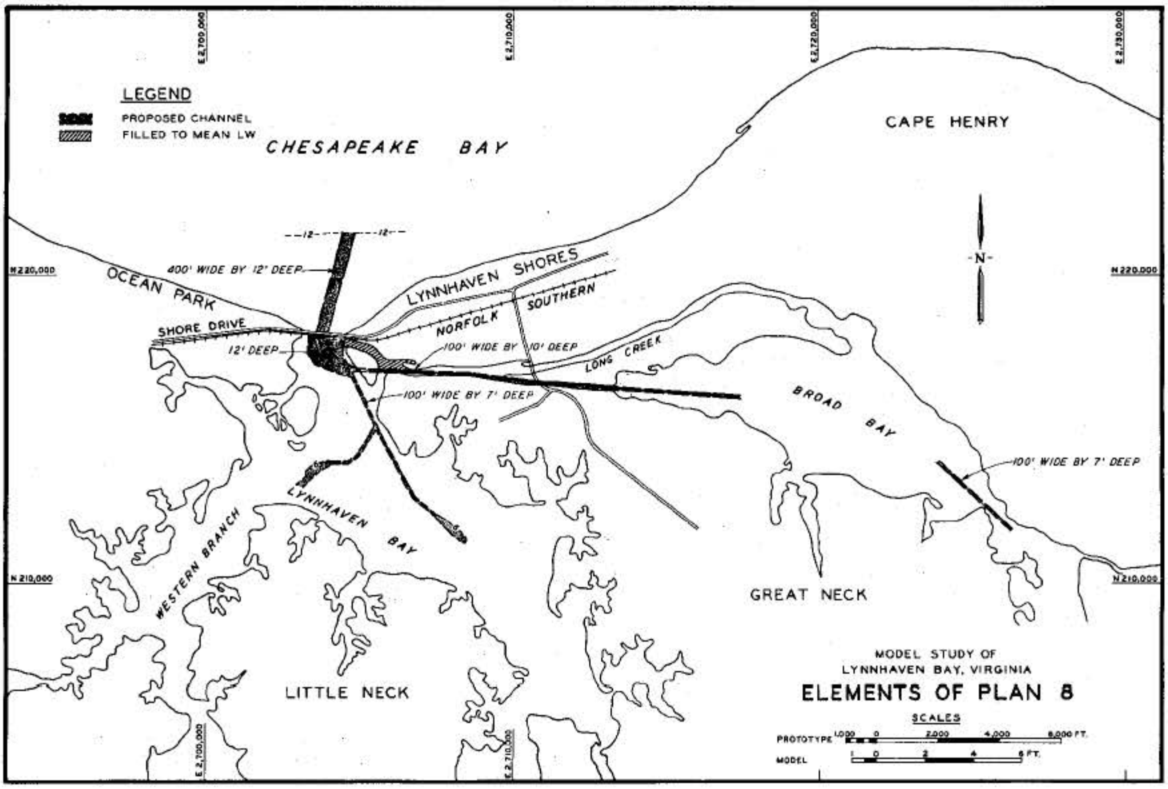


Fig. 13. Elements of plan 8

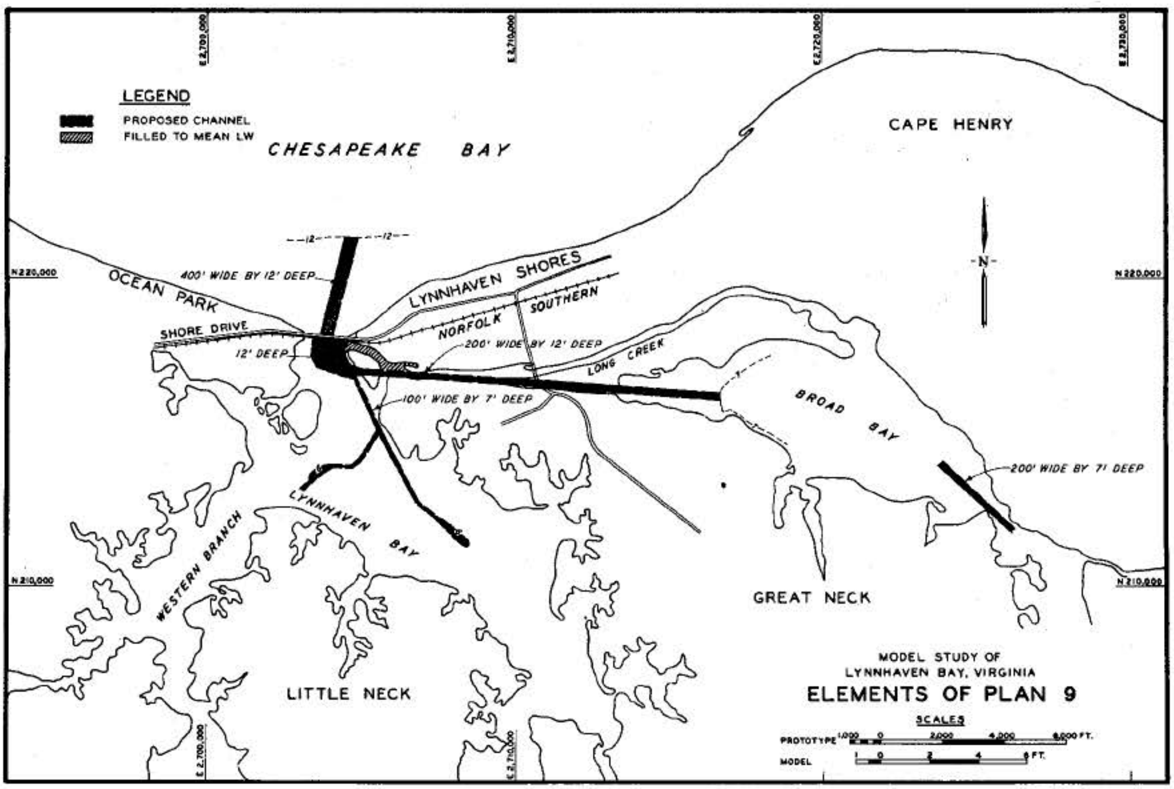


Fig. 14. Elements of plan 9

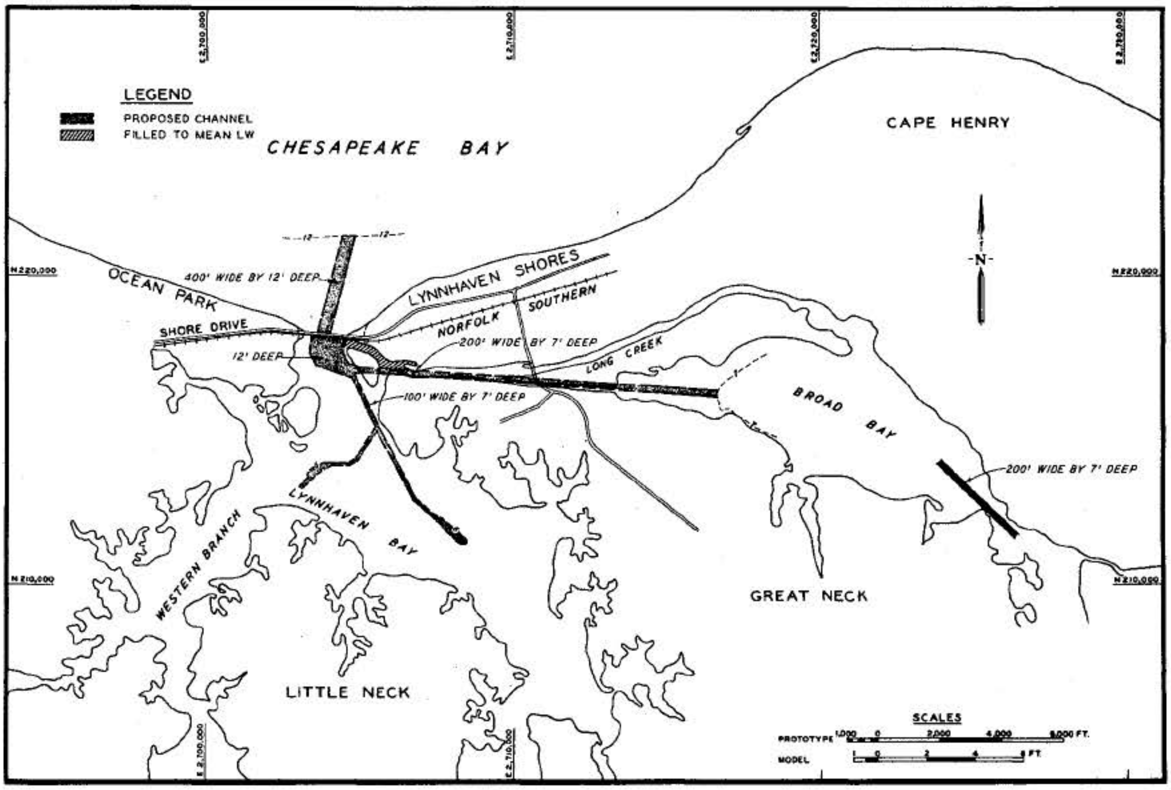


Fig. 15. Elements of plan 10

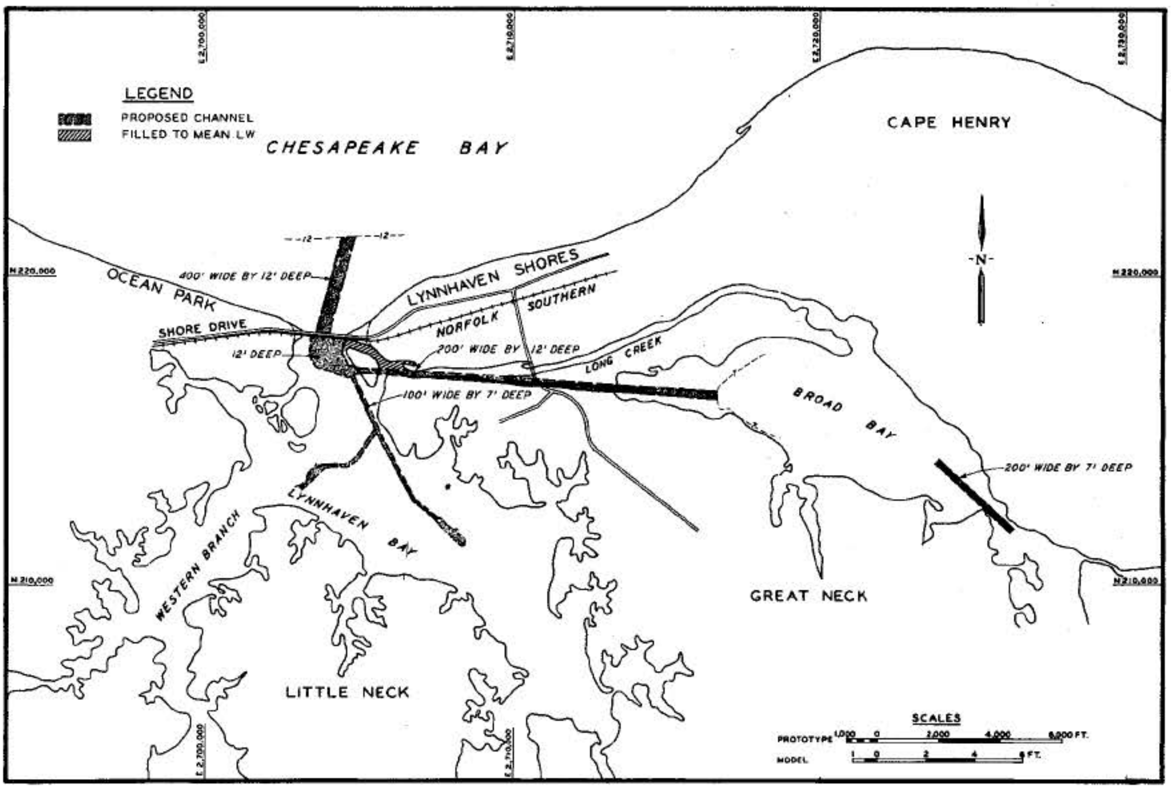


Fig. 16. Elements of plan 11

of one-third of the fill on the east side of the inlet effected slight increases in tidal ranges throughout the interior bay system. However, removal of additional portions of the fills on each side of the inlet (plans 10 and 11) failed to indicate further increases in tidal ranges.

Discussion of Results

59. Field studies conducted by the Norfolk District indicate that the interchange of water necessary for shellfish cultivation in the area under study can be provided with a tidal range in the upper reaches of Broad and Linkhorn Bays equivalent to 25 per cent of the range at station 1 in Chesapeake Bay. The range of tide reproduced at station 1 for the tests herein reported was 3.0 ft; therefore, with this tidal reproduction, the required range of tide in Broad and Linkhorn Bays is approximately 0.75 ft.

60. The results of model tests indicate that any of plans 1, 2, 7, and 8 would provide tidal ranges in Broad and Linkhorn Bays equal to or slightly greater than that considered necessary for shellfish cultivation. Modification of plan 7 by removing portions of the artificial fills extending into the inlet (plans 9, 10, and 11) would also provide a tidal range in Broad and Linkhorn Bays slightly greater than that required. Plans 3, 4, 5, and 6 did not provide the full range desired. Since the tidal range in Lynnhaven Bay proper for existing conditions was not affected appreciably by any of the plans tested, it is believed that the tidal range in Broad and Linkhorn Bays is controlled primarily by the width and depth of the Lynnhaven Bay-Broad Bay channel and not by the cross-sectional area of the channel outside the bridges. This point is

further demonstrated by a comparison of the results obtained during tests of plans 2 and 7. The interior channels of these two plans were identical, the only differences between the plans being that plan 2 included an 18-ft-deep outer channel while plan 7 included a 12-ft-deep outer channel. Tidal ranges measured throughout the interior bay system during tests of these two plans were, for all practical purposes, identical.

61. It appears that a Lynnhaven Bay-Broad Bay channel 200 ft wide by 7 ft deep, or 100 ft wide by 10 ft deep, will provide the desired tidal range throughout Broad and Linkhorn Bays. Therefore, selection of the channel to be dredged in the prototype may be based on its merits from the viewpoints of navigation and maintenance. If the 7-ft-deep channel is adequate for navigation, it might require less maintenance than would the 10-ft-deep channel, since there would be less danger of sloughing of the sides. However, this is probably a very minor point since the difference in depth of the two channels is only 3.0 ft.

62. Current directions in and adjacent to the westerly end of the Lynnhaven Bay-Broad Bay channel during tests of plans which involved relocation of this channel (plans 5 through 11) indicated that navigation conditions would be improved appreciably by the realignment. Tests of plans 1 through 4, which did not include the realignment, indicated that hazardous crosscurrents would obtain in the navigation channel just inside the railroad bridge. During tests of plans incorporating the realignment, however, there was no indication of crosscurrents that might be dangerous to boats of any size.

63. Current velocities in the Lynnhaven Bay-Broad Bay channel were increased to some extent by each of the improvement plans tested.

The maximum velocity measured in this channel (ebb velocity during test of plan 6) was about 5.3 ft per sec, which might be dangerous to navigation by small boats. It is considered probable that some scour of this channel would occur because of the relatively high velocity currents.

Effects of bridges on tidal flow

64. Upon completion of tests of plans 1 through 4, a short supplementary test was conducted to determine whether or not the existing bridges offered appreciable resistance to tidal flow through the inlet. This test was made with plan-4 conditions installed in the model. Gage readings were obtained at stations 1, 12, and 23, and at additional points designated stations A, B, C, D, and E on fig. 17. From gage readings at these 8 stations, the profiles of high and low water were

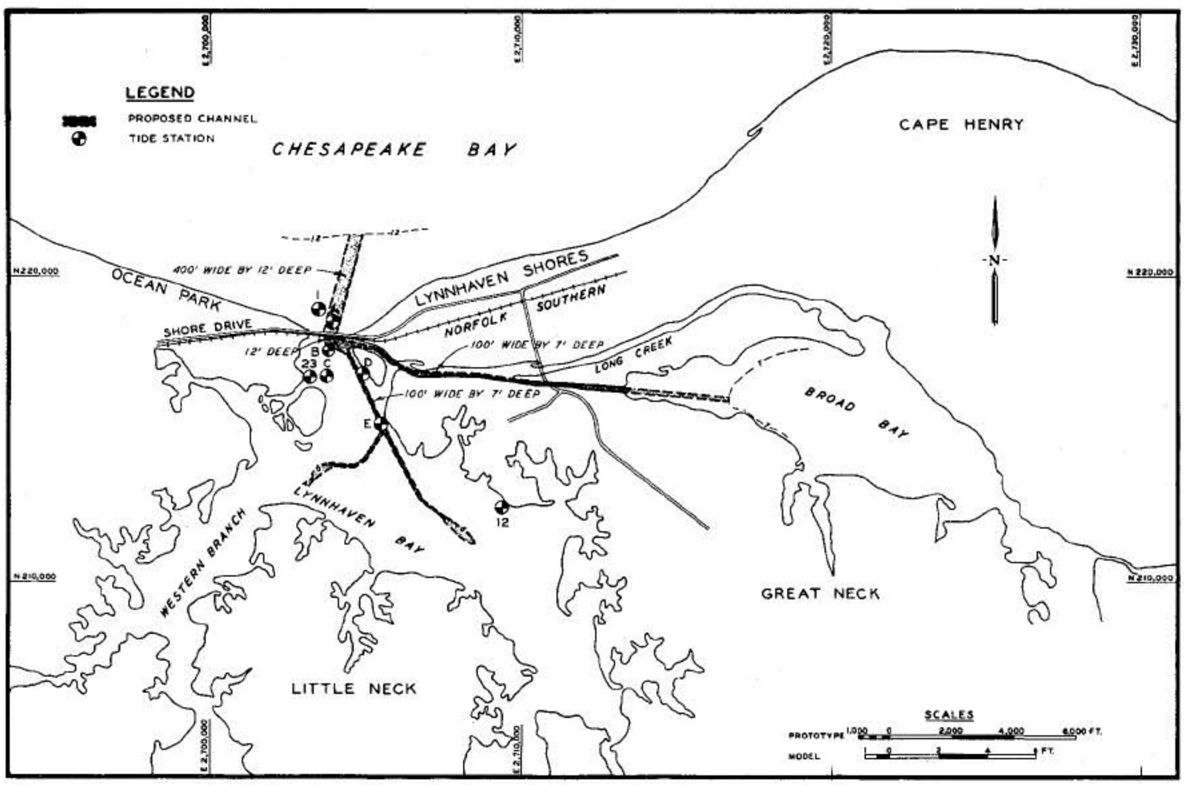


Fig. 17. Location of gages

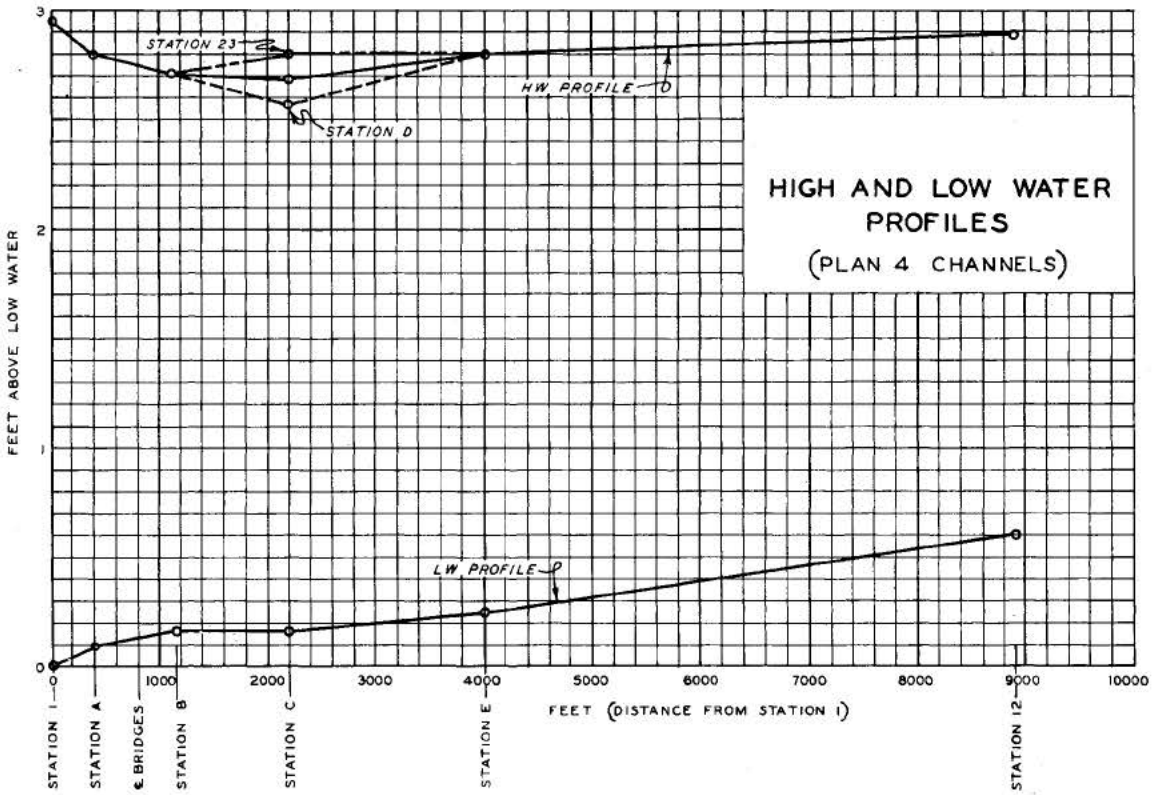


Fig. 18

determined and plotted as shown on fig. 18. Examination of these profiles does not indicate a sharp break in water-surface elevation at the location of the bridges; therefore, it is believed that the existing bridges do not afford appreciable resistance to tidal flow. However, the bridges do appear to effect local increases in current velocities through and adjacent to the bridge sections.

65. It will be noted on fig. 18 that three separate high-water profiles are plotted between stations B and E, one profile passing through the high-water elevation for station 23, one for station C, and one for station D. As shown on fig. 17 these latter three stations are located on a line approximately at right angles to the inlet channel, station 23 being located near the west bank, station C near the center

of the channel, and station D near the east bank, and also near the entrance of the Long Creek channel into Lynnhaven Bay. Measurements obtained at these gages indicate that the elevation of high water on the east side of the inlet (station D) is approximately 0.2 ft lower than that on the west side (station 23), there being a definite slope across the full width of the inlet. This transverse slope is attributed to the drawdown caused by flow of water through Long Creek to Broad and Linkhorn Bays.

PART V: NARRATIVE OF TESTS, MOVABLE-BED MODEL

First Series

Plan A

66. Plan A (see plate 53) was similar to plan 2 of the fixed-bed tests. It consisted of dredging an entrance channel 400 ft wide and 18 ft deep, beginning at the 18-ft contour of depth in Chesapeake Bay and extending to the highway bridge across Lynnhaven Inlet. No jetties were incorporated in plan A.

67. The results of the test of plan A are shown on plates 53 and 54 and in table 4. The controlling depth in the navigation channel at the end of the test was -14 ft; however, a bar having a crest elevation of about -11 ft extended into the east side of the channel about 400 ft north of sounding range 19, and a second bar having a crest elevation of about -4 ft extended well into the west side of the channel at about range 20. Formation of the bar on the west side of the channel began early in the test, and had progressed to about the extent indicated on plate 53 by the end of the 9th or 10th cycle of operation. The bar on the east side formed more slowly, and began to encroach on the channel during about the 9th cycle of operation. While formation of this bar was appreciably slower than that on the west side, it probably would have continued to grow at a slow rate until the channel was completely filled. Waves of appreciable size entered and passed up the 18-ft channel, and growth of the bar on the west side appeared to be accelerated by the scouring action of these waves breaking on the west side of the channel. As shown in table 4, the volume of material introduced at the east end of

the model was 92,600 cu yd, and that removed at the west end was 85,300 cu yd. A total of 355,600 cu yd was removed from the navigation channel at the end of the test to restore the channel to its original dimensions.

Plan B

68. Plan B (see plate 55) was similar to plan 4 of the fixed-bed tests. It consisted of dredging an entrance channel 400 ft wide and 12 ft deep, beginning at the 12-ft contour of depth in Chesapeake Bay and extending to the highway bridge across Lynnhaven Inlet. No jetties were incorporated in plan B.

69. The results of the test of plan B are shown on plates 55 and 56 and in table 4. The controlling depth in the navigation channel at the end of the test was -4 ft; however, this depth was on the crest of a bar which extended completely across the channel about 600 ft north of sounding range 19. The width of this bar was about 500-600 ft, and fairly deep water prevailed throughout the remainder of the channel. A second bar encroached slightly on the channel from the west side at about range 20, but development of this bar was considerably slower than had been noted during the test of plan A. The outer bar formation (north of range 19) had progressed appreciably by the end of 7 cycles of operation, and had progressed to about the extent shown on plate 55 by the end of 12 cycles. Following the 12th cycle, it appeared that material moved completely across the channel on the crest of the bar and continued its movement in a westerly direction. There appeared to be a tendency toward shifting of the channel in a westerly direction, since the line of deepest water at the end of the test was along or slightly west of the west channel limit. A total of 92,600 cu yd of material was introduced at the

east end of the model during the test, and 80,600 cu yd were removed from the west end. Channel shoaling during the test amounted to 118,500 cu yd (see table 4).

Plan C

70. Plan C (see plate 57) was similar to plan 3 of the fixed-bed tests except for the length of the jetties. It consisted of dredging an entrance channel 400 ft wide and 12 ft deep, beginning at the 12-ft contour of depth in Chesapeake Bay and extending to the highway bridge across Lynnhaven Inlet. The channel was protected by parallel jetties 3300 ft long, 850 ft apart, and with crest elevations of +6 ft. The jetties extended from the 8-ft contour of depth in Chesapeake Bay to the shore adjacent to each end of the highway bridge across Lynnhaven Inlet.

71. The results of the test of plan C are shown on plates 57 and 58 and in table 4. The controlling depth in the navigation channel at the end of the test was -9 ft, and a 12-ft depth prevailed except in the outer 800 ft of the dredged channel. The shoal in the outer portion of the channel was caused partially by material moving around the outer end of the east jetty and partially by material being carried over the crest of the east jetty about 500 to 800 ft north of range 19. Movement of material around the outer end of the east jetty and into the channel was noted from the beginning of the test. The movement of material over the crest of the east jetty did not begin until the end of the 5th cycle of operation, at which time a bar of appreciable height had been built up to the east of the east jetty. The movement of material into the channel from both sources described above was fairly slow; however, it is probable that this movement would have continued at a decreasing rate until the

channel reached a stable condition having a somewhat smaller cross-sectional area than that shown on plate 57. It was noted that some material moved completely across the channel beyond the outer ends of the jetties. This movement probably would have increased in volume as the outer sections of the channel shoaled. The total volume of material introduced into the east end of the model was 92,600 cu yd and the amount removed from the west end was 135,600 cu yd. The amount of shoaling which occurred in the navigation channel during the test was 92,400 cu yd (see table 4).

Plan D

72. Plan D (see plate 59) was identical to plan C except that the jetties were extended to the 12-ft contour of depth in Chesapeake Bay, or a distance of 150 ft beyond the ends of the plan-C jetties (same as plan 3 of the fixed-bed tests).

73. The results of the test of plan D are shown on plates 59 and 60 and in table 4. The effects of this plan in the model were practically identical to those of plan C, as may be noted by comparing plates 57 and 58 with plates 59 and 60. The only appreciable difference noted was that extension of the jetties appeared to decrease the movement of material around the outer end of the east jetty and into the channel, and also the movement across the channel beyond the outer ends of the jetties. These effects may be noted in table 4, which indicates that shoaling of the channel was slightly less than that which occurred during the test of plan C, and also the amount of material removed from the west end of the model was decreased to some extent. This indicates that extension of the jetties would trap and impound a slightly greater amount of the alongshore

littoral drift. The amount of material introduced into the east end of the model during the test was the same as that introduced during the test of plan C (92,600 cu yd).

Plan E

74. Plan E (see plate 61) was identical to plan D except that the jetties were extended to the 18-ft contour of depth in Chesapeake Bay, or a distance of 200 ft beyond the ends of the plan-D jetties.

75. The results of the test of plan E are shown on plates 61 and 62 and in table 4. The controlling depth in the navigation channel at the end of the test was about -9 ft. The trends toward reduction of movement around the end of the east jetty and into the channel, and also across the channel beyond the ends of the jetties, were more marked with the longer jetties of plan E. This was accompanied by further reductions in both shoaling of the navigation channels and movement of material out of the west end of the model (see table 4). The amount of material introduced into the east end of the model during the test was 92,600 cu yd.

Discussion of results

76. Comparison of the results of tests involving jetties (plans C, D, and E) indicated that shoaling of the channel by movement of material around the outer end of the east jetty decreased progressively as the lengths of the jetties were increased. However, the tests also indicated that greater volumes of alongshore littoral drift were impounded as the lengths of the jetties were increased, as shown by the progressively decreasing volume of material moved out the west end of the model. It was not possible to determine accurately the amounts of material moved across the crest of the east jetty by wave action during the tests;

however, indications were that this volume was not affected appreciably by the lengths of the jetties.

77. The results of tests without jetties (plans A and B) indicate that the 12-ft-deep channel would be considerably less subject to shoaling than the 18-ft-deep channel. This difference is attributed principally to the following two factors: (a) the greater depth of the 18-ft-deep channel allowed waves of appreciable height to run up the channel and break on its west bank, thus causing scour of the bank and rapid formation of a bar on the west side of the channel at range 20; and (b) the greater channel depth did not permit movement of as much of the littoral drift across the channel near its outer end as did the 12-ft-deep channel.

78. Comparison of results of the test of the 12-ft-deep channel without jetties (plan B) with results of tests involving jetties (plans C, D, and E) indicates that the jetties to the 8-ft depth contour reduced shoaling by about 22 per cent, those to the 12-ft contour reduced shoaling by about 28 per cent, and those to the 18-ft contour reduced shoaling by about 37 per cent. Inasmuch as the greatest reduction in shoaling effected by jetties (37 per cent for plan E) was not very great, the possibility is suggested that still shorter jetties than those of plan C might be used, or that a channel unprotected by jetties might be preferable on an over-all basis to one protected by jetties. The shoaling which occurred during the test of plan B (12-ft channel without jetties) was largely confined to one section of the channel about 500 or 600 ft in length. Unless the value of jetties as protection to navigation carries considerable weight, it might be more satisfactory and economical to maintain a comparatively short reach of channel by dredging

than by the construction of jetties. It is pointed out that the accelerated movement of material which would probably occur during a storm of great intensity might change the entire pattern of shoaling indicated by the model; however, it is believed that such effect would be about the same whether or not jetties were constructed. Since the relatively small waves reproduced during model tests caused movement of material over the crest of the east jetty, it is almost certain that larger waves accompanying severe storms would greatly accelerate such movement.

79. The tendency for the channel to shift in a westerly direction, demonstrated during the test of plan B, suggests the possibility that the angle of the dredged channel might be shifted slightly in that direction with beneficial results. It is believed that the importance of this factor would be increased if jetties were involved, since the angle of the jetties would be inclined in the direction of the littoral drift instead of against the direction of the drift as was the case for all jetty plans tested thus far in the model. Inclination of the jetties in the direction of the littoral drift should result in a greater volume of the drift passing around the ends of the jetties, with a corresponding reduction in the amount of drift impounded to the east of the jetties and an increase, or less decrease, in the amount moving on to the west of Lynnhaven Inlet. It is also possible that the amount of material moving around the outer end of the east jetty and into the navigation channel might be decreased by shifting the outer ends of the jetties in a westerly direction. The prevailing direction from which waves approach Lynnhaven Inlet is about northeast; therefore, shifting the outer ends of the jetties to the west would probably prevent waves of appreciable height from running up the

channel and scouring the side slopes, especially on the west side of the channel.

Second Series

80. Analysis of the results of tests of plans A-E suggested several modifications which might prove desirable. Plans F-J were evolved and tested to determine the effects of these modifications.

Plan F

81. Plan F (see plate 63) consisted of a dredged entrance channel 400 ft wide and 12 ft deep, beginning at the 12-ft contour of depth in Chesapeake Bay and extending to the highway bridge across Lynnhaven Inlet. Arrowhead jetties with crest elevations of +6 ft were constructed for protection of the channel. These jetties extended from the 12-ft contour of depth in Chesapeake Bay shoreward to the +6-ft contour.

82. The results of the test of plan F are shown on plates 63 and 64 and in table 5. The controlling depth of the channel at the end of the test was -12 ft, which was the prevailing depth except on the edges of the channel where slight shoaling had occurred. This shoaling of the channel was caused partially by material moving around the outer end of the east jetty and partially by material eroded by wave action from the area between the west side of the channel and the west jetty. A bar formation started on the first cycle of the test between sounding range 6 and the east jetty. This formation increased in size and moved shoreward, overtopping the jetty during the third cycle. In previous tests with parallel jetties, material overtopping the jetties was deposited directly in the channel; however, owing to the greater area between the

channel and the arrowhead jetties, this action had not progressed sufficiently to cause serious channel shoaling by the end of the test. The bar formation on the west side of the west jetty overtopped the jetty on the third cycle, and slowly spread out and moved landward parallel to the channel. The total volume of material introduced into the east end of the model was 92,600 cu yd, and 85,300 cu yd were removed from the west end. Channel shoaling during the test amounted to 19,000 cu yd.

Plan G

83. Plan G (see plate 65) consisted of a dredged entrance channel 400 ft wide and 12 ft deep, beginning at the 12-ft contour of depth in Chesapeake Bay and extending to the highway bridge across Lynnhaven Inlet. This plan was identical to plan B except that the channel alignment was turned 10 degrees to the west of the plan-B channel. No jetties were incorporated in plan G.

84. The results of the test of plan G are shown on plates 65 and 66 and in table 5. The controlling depth in the navigation channel was +3.0 ft, the elevation at the crest of a bar approximately 1000 ft wide which extended completely across the channel at sounding range 19. Realignment of the channel apparently accelerated formation of this bar due to the alignment of the breaking waves with respect to the channel alignment. The volume of material introduced at the east end of the model was 92,600 cu yd, and that removed at the west end was 94,800 cu yd. A total of 151,700 cu yd was removed from the navigation channel at the end of the test to restore it to original dimensions.

Plan H

85. Plan H (see plate 67) consisted of a dredged entrance channel

400 ft wide and 12 ft deep, beginning at the 12-ft contour of depth in Chesapeake Bay and extending to the highway bridge across Lynnhaven Inlet. The channel was protected by parallel jetties 3000 ft long, 850 ft apart, and with crest elevations of +6 ft. This plan was identical to plan C except that the jetties extended to the 6-ft contour of depth in Chesapeake Bay instead of the 8-ft contour.

86. The results of plan H are shown on plates 67 and 68 and in table 5. The controlling depth in the navigation channel was -9 ft. The shoal in the navigation channel was caused by material moving over the crest of the east jetty about 500 to 800 ft north of sounding range 19, and by material moving around the end of the east jetty and up the channel. The shorter jetties of plan H accelerated the movement of material up the channel and increased the total shoaling over that of plan B by 16 per cent. The total volume of material introduced into the east end of the model was 92,600 cu yd, and 71,100 cu yd were removed from the west end. Channel shoaling during the test amounted to 137,500 cu yd.

Plan I

87. Plan I (see plate 69) consisted of a dredged entrance channel on the same alignment as plan B, 400 ft wide and 12 ft deep, beginning at the 12-ft contour of depth in Chesapeake Bay and extending to the highway bridge across Lynnhaven Inlet. Plan I was identical to plan C except that the channel was protected by a single jetty constructed parallel to and east of the channel, extending from the 12-ft contour of depth in the Chesapeake Bay to the east end of the highway bridge across Lynnhaven Inlet.

88. The results of plan I are shown on plates 69 and 70 and in

table 5. The controlling depth in the channel at the end of the test was -6 ft; however, shoaling was confined to a comparatively short section of the channel near sounding range 19. The volume of material introduced in the east end of the model was 92,600 cu yd, and 71,100 cu yd were removed from the west end of the model. A total of 87,700 cu yd was dredged from the channel after completion of the test.

Plan J

89. Plan J (see plate 71) consisted of a dredged entrance channel similar to plan A, 400 ft wide and 18 ft deep, beginning at the 18-ft contour of depth in Chesapeake Bay and extending to the highway bridge across Lynnhaven Inlet, together with the most favorable channel alignment and arrangement of jetties as determined from tests of the 12-ft channel. The channel was constructed on the plan-B alignment, and was protected by arrowhead jetties on the east and west sides of the channel, beginning at the 12-ft contour of depth in Chesapeake Bay and extending shoreward to the +6-ft contour.

90. The results of plan J are shown on plates 71 and 72 and in table 5. The controlling channel depth at the end of the test was -17 ft. The slight shoaling that occurred in the channel was caused by material moving around the outer end of the east jetty, together with the material moved from the area immediately adjacent to the outer portion of the channel by wave action. Material overtopping the east jetty spread out in the area between the channel and the jetty, and very little of it reached the channel during the test. The total volume of material introduced into the east end of the model was 92,600 cu yd and that removed at the west end was 90,100 cu yd. A total of 80,600 cu yd was removed

from the navigation channel at the end of the test to restore it to its original dimensions.

Discussion of results

91. The results of these tests indicated less shoaling of the entrance channel for plans involving arrowhead jetties than for those involving parallel jetties. This is believed attributable to the following factors: (a) more material was impounded to the east of the arrowhead jetties than for the parallel jetties; (b) the movement of material past the outer ends of the arrowhead jetties was accelerated owing to the lesser angle of the east jetty with respect to the direction of the alongshore current; and (c) material overtopping the east arrowhead jetty was impounded in the comparatively large area between the jetty and the channel and therefore did not enter the channel to form a shoal.

92. Realignment of the channel 10 degrees to the west (plan G) resulted in formation of a more extensive bar across the channel than occurred for plan B. The exact reason for this increased bar formation could not be determined, but it was probably due to the alignment of the channel with respect to the direction of the alongshore currents and the alignment of the breaking waves.

93. Decreasing the length of the jetties to the 6-ft contour of depth (plan H) increased the amount of shoaling in the channel in greater proportion than was indicated by the results of tests of plans C, D, and E. Less material was impounded on the east side of the east jetty, and the material moving around the end of the east jetty moved up instead of across the channel causing considerable shoaling in the outer portion of the channel.

94. The results of plan I, which incorporated a single east jetty as protection for the navigation channel, indicated that a single jetty would provide about the same degree of protection against shoaling as would parallel jetties of the same length.

PART VI: CONCLUSIONS

Fixed-bed Model

95. The following conclusions are drawn from an analysis of the results of all tests conducted in the Lynnhaven Bay (fixed-bed) model:

- a. A Lynnhaven Bay-Broad Bay Channel 200 ft wide by 7 ft deep, or 100 ft wide by 10 ft deep, would provide the desired tidal range in the upper reaches of Broad and Linkhorn Bays.
- b. An outer channel 400 ft wide by 12 ft deep would provide the desired tidal flow into and out of the interior bay system. From a hydraulic viewpoint, it is considered that the depth of this channel could be decreased to less than 12 ft without adversely affecting tidal ranges throughout the interior bay system; however, it is understood that a depth of 12 ft in this channel would be necessary for navigation.
- c. Realignment of the westerly end of the Lynnhaven Bay-Broad Bay channel would be advantageous to navigation by eliminating crosscurrents in and adjacent to this channel.
- d. The existing bridges do not offer an appreciable obstruction to tidal flow into and out of the inlet; however, it is believed that navigation through the bridges would be improved by incorporation of a wider opening for this purpose.

Movable-bed Model

96. It is stressed that the results of the movable-bed tests can be evaluated only on a comparative or qualitative basis. As before stated, quantitative data could not be obtained from the model since the rate of movement of bed material in the prototype, from which the model time scale for bed movement must be derived, could not be determined.

97. On a comparative basis, it appears that plans B and C of the first series of movable-bed tests are superior to any other of the plans

tested. If the protection to navigation which would be afforded by jetties is of primary importance to solution of the prototype problem, plan C would of course be superior to plan B. If, however, protection to navigation is of minor importance and the problem is one of maintaining tidal flow into and out of Lynnhaven Inlet at the lowest possible cost, it is believed that plan B would be more satisfactory and economical than plan C. This opinion is based on the relatively small reduction in channel shoaling (about 22 per cent) effected by the jetties of plan C.

98. For the second series of movable-bed tests it is believed that plan I would afford the greatest protection to the entrance channel at the lowest possible cost-benefit ratio. However, since the shoaling rate per unit of time could not be determined during the model tests, it is recommended that the entrance channel first be dredged without a protective structure of any type. Then, if it appears that reshoaling of the channel will progress at a sufficiently rapid rate to warrant adoption of some corrective improvement works, construction of plan I, or some modification thereof, could be undertaken. In this connection it is pointed out that shoaling of the channel caused by material overtopping the plan I jetty (or any of the plans involving such a jetty) could be reduced by moving the east jetty somewhat farther away from the channel. It is believed that the larger impounding area between the channel and the east arrowhead jetty was largely responsible for the lesser rate of shoaling noted during tests of the arrowhead jetties.

TABLES

Table 1

EFFECTS OF PLANS ON ELEVATIONS OF HIGH AND LOW WATER

(Elevations in Ft, Prototype, above L.W., Norfolk District Datum)

	Tide Observation Stations													
	Sta. 5 Long Creek		Sta. 6 Broad Bay		Sta. 8 Broad-Linkhorn Bays		Sta. 9 Linkhorn Bay		Sta. 12 Lynnhaven Bay		Sta. 13 Eastern Branch		Sta. 18 Western Branch	
Test	H.W.	L.W.	H.W.	L.W.	H.W.	L.W.	H.W.	L.W.	H.W.	L.W.	H.W.	L.W.	H.W.	L.W.
Base	2.70	0.40	2.20	1.95	2.15	1.95	2.15	1.95	2.75	0.60	2.90	0.80	2.85	0.90
Plan 1	2.40	0.55	2.30	1.20	2.30	1.35	2.25	1.30	2.80	0.60	2.85	0.70	2.75	0.65
Plan 2	2.50	0.70	2.30	1.30	2.25	1.35	2.15	1.35	2.70	0.65	2.75	0.60	2.70	0.75
Plan 3	2.60	0.65	2.15	1.70	2.10	1.60	2.10	1.60	2.75	0.60	2.80	0.65	2.75	0.65
Plan 4	2.60	0.70	2.10	1.60	2.00	1.50	2.05	1.50	2.90	0.60	2.80	0.55	2.70	0.65
Plan 5	2.60	0.40	2.10	1.60	2.10	1.50	2.10	1.55	2.70	0.50	2.80	0.55	2.70	0.65
Plan 6	2.50	0.70	2.10	1.45	2.05	1.45	2.10	1.40	2.70	0.65	2.70	0.65	2.70	0.70
Plan 7	2.50	0.60	2.20	1.30	2.25	1.35	2.20	1.30	2.70	0.60	2.70	0.55	2.70	0.70
Plan 8	2.50	0.65	2.15	1.20	2.30	1.30	2.30	1.30	2.80	0.65	2.70	0.55	2.80	0.70
Plan 9	2.40	0.50	2.30	1.00	2.30	1.05	2.30	1.05	2.70	0.50	2.70	0.50	2.75	0.75
Plan 10	2.50	0.50	2.15	1.00	2.25	1.05	2.25	0.95	2.70	0.50	2.60	0.45	2.85	0.85
Plan 11	2.40	0.50	2.30	1.10	2.45	1.15	2.30	0.95	2.70	0.50	2.65	0.40	2.80	0.75

Notes: High-water elevation at station 1 (Chesapeake Bay) is + 3.00 ft. Low-water elevation at station 1 is 0.0. Location of tide stations shown on fig. 2.

Table 2

EFFECTS OF PLANS ON TIDAL RANGE

(Range in Ft, Prototype)

Test	Sta. 5 Long Creek Tidal Range	Sta. 5 Long Creek Per Cent of Chesapeake Bay Range	Sta. 6 Broad Bay Tidal Range	Sta. 6 Broad Bay Per Cent of Chesapeake Bay Range	Sta. 8 Broad-Linkhorn Bays Tidal Range	Sta. 8 Broad-Linkhorn Bays Per Cent of Chesapeake Bay Range	Sta. 9 Linkhorn Bay Tidal Range	Sta. 9 Linkhorn Bay Per Cent of Chesapeake Bay Range	Sta. 12 Lynnhaven Bay Tidal Range	Sta. 12 Lynnhaven Bay Per Cent of Chesapeake Bay Range	Sta. 13 Eastern Branch Tidal Range	Sta. 13 Eastern Branch Per Cent of Chesapeake Bay Range	Sta. 18 Western Branch Tidal Range	Sta. 18 Western Branch Per Cent of Chesapeake Bay Range
Base	2.30	80	0.25	8	0.20	7	0.20	7	2.15	72	2.10	70	1.95	65
Plan 1	1.85	62	1.10	37	0.95	32	0.95	32	2.20	73	2.15	72	2.10	70
Plan 2	1.80	60	1.00	33	0.90	30	0.80	27	2.05	68	2.15	72	1.95	65
Plan 3	1.95	65	0.45	15	0.50	17	0.50	17	2.15	72	2.15	72	2.10	70
Plan 4	1.90	63	0.50	17	0.50	17	0.55	18	2.30	77	2.25	75	2.05	68
Plan 5	2.20	73	0.50	17	0.60	20	0.55	18	2.20	73	2.25	75	2.05	68
Plan 6	1.80	60	0.65	22	0.60	20	0.70	23	2.05	68	2.05	68	2.00	67
Plan 7	1.90	63	0.90	30	0.90	30	0.90	30	2.10	70	2.15	72	2.00	67
Plan 8	1.85	62	0.95	32	1.00	33	1.00	33	2.15	72	2.15	72	2.10	70
Plan 9	1.90	63	1.30	43	1.25	42	1.25	42	2.20	73	2.20	73	2.00	67
Plan 10	2.00	67	1.15	38	1.20	40	1.30	43	2.20	73	2.15	72	2.00	67
Plan 11	1.90	63	1.20	40	1.30	43	1.35	45	2.20	73	2.25	75	2.05	68

Note: Tidal range at Station 1 (Chesapeake Bay) is 3.00 ft. Locations of tide stations shown on fig. 2.

Table 3

EFFECTS OF PLANS ON MAXIMUM CURRENT VELOCITIES

(Velocities in Ft per sec, Prototype)

	Velocity Observation Stations															
	Station 3				Station 9				Station 11				Long Creek			
			Increase or Decrease				Increase or Decrease				Increase or Decrease				Increase or Decrease	
Test	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb
Base	2.0	2.1			2.6	3.0			1.2	2.5			1.6	2.2		
Plan 1	2.2	2.2	+0.2	+0.1	3.0	3.1	+0.4	+0.1	3.0	5.0	+1.8	+2.5	3.2	4.5	+1.6	+2.3
Plan 2	1.9	2.3	-0.1	+0.2	3.0	3.1	+0.4	+0.1	2.9	4.7	+1.7	+2.2	3.3	4.4	+1.7	+2.2
Plan 3	1.9	2.2	-0.1	+0.1	2.6	3.3	0.0	+0.3	1.6	3.9	+0.4	+1.4	3.4	4.1	+1.8	+1.9
Plan 4	2.2	2.2	+0.2	+0.1	2.9	3.4	+0.3	+0.4	1.6	4.3	+0.4	+1.8	3.4	4.3	+1.8	+2.1
Plan 5	1.6	2.4	-0.4	+0.3	2.0	3.9	-0.6	+0.9	2.3	4.5	+1.1	+2.0	2.9	4.5	+1.3	+2.3
Plan 6	1.8	2.7	-0.2	+0.6	2.1	3.9	-0.5	+0.9	2.6	5.6	+1.4	+3.1	4.1	5.3	+2.5	+3.1
Plan 7	2.1	2.0	+0.1	-0.1	2.1	3.6	-0.5	+0.6	2.3	4.1	+1.2	+1.6	3.6	4.3	+2.0	+2.1
Plan 8	1.9	2.2	-0.1	+0.1	2.5	4.1	-0.1	+1.1	3.1	5.3	+1.9	+2.8	3.4	4.5	+1.8	+2.3
Plan 9	1.7	2.6	-0.3	+0.5	1.9	5.6	-0.7	+2.6	3.4	6.0	+2.2	+3.5	3.6	4.5	+2.0	+2.3
Plan 10	1.6	2.4	-0.4	+0.3	1.6	4.7	-1.0	+1.7	3.2	6.0	+2.0	+3.5	3.9	4.7	+2.3	+2.5
Plan 11	1.7	2.3	-0.3	+0.2	1.9	5.6	-0.7	+2.6	3.3	6.0	+2.1	+3.5	4.3	4.5	+2.7	+2.3

Note: Tidal range at Station 1 (Chesapeake Bay) is 3.00 ft. Locations of velocity stations shown on fig. 2.

Table 4

EFFECTS OF PLANS ON SHOALING

First Series

Plan	Material Introduced at East End of Model (Cu Yd)	Material Removed at West End of Model (Cu Yd)	Material Removed from Channel (Cu Yd)	Percentile Increase or Decrease from Plan B
A	92,600	85,300	355,600	200
B	92,600	80,600	118,500	0
C	92,600	135,600	92,400	-22
D	92,600	118,500	85,300	-28
E	92,600	91,100	75,000	-37

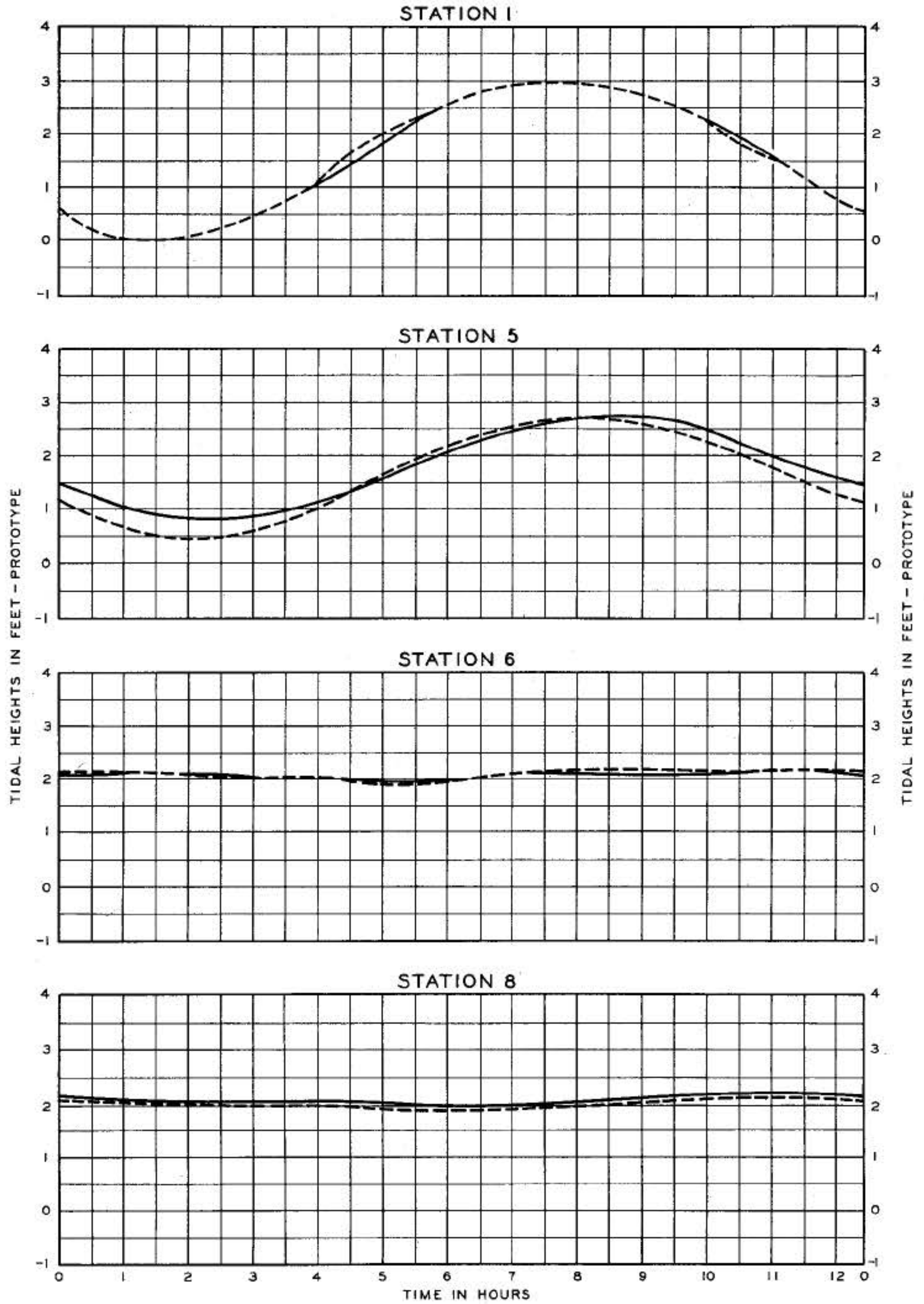
Table 5

EFFECTS OF PLANS ON SHOALING

Second Series

Plan	Material Introduced at East End of Model (Cu Yd)	Material Removed at West End of Model (Cu Yd)	Material Removed from Channel (Cu Yd)	Percentile Increase or Decrease from Plan B
F	92,600	85,300	19,000	-84
G	92,600	94,800	151,700	28
H	92,600	71,100	137,500	16
I	92,600	71,100	87,700	26
J	92,600	90,100	80,600	-32

PLATES



LEGEND

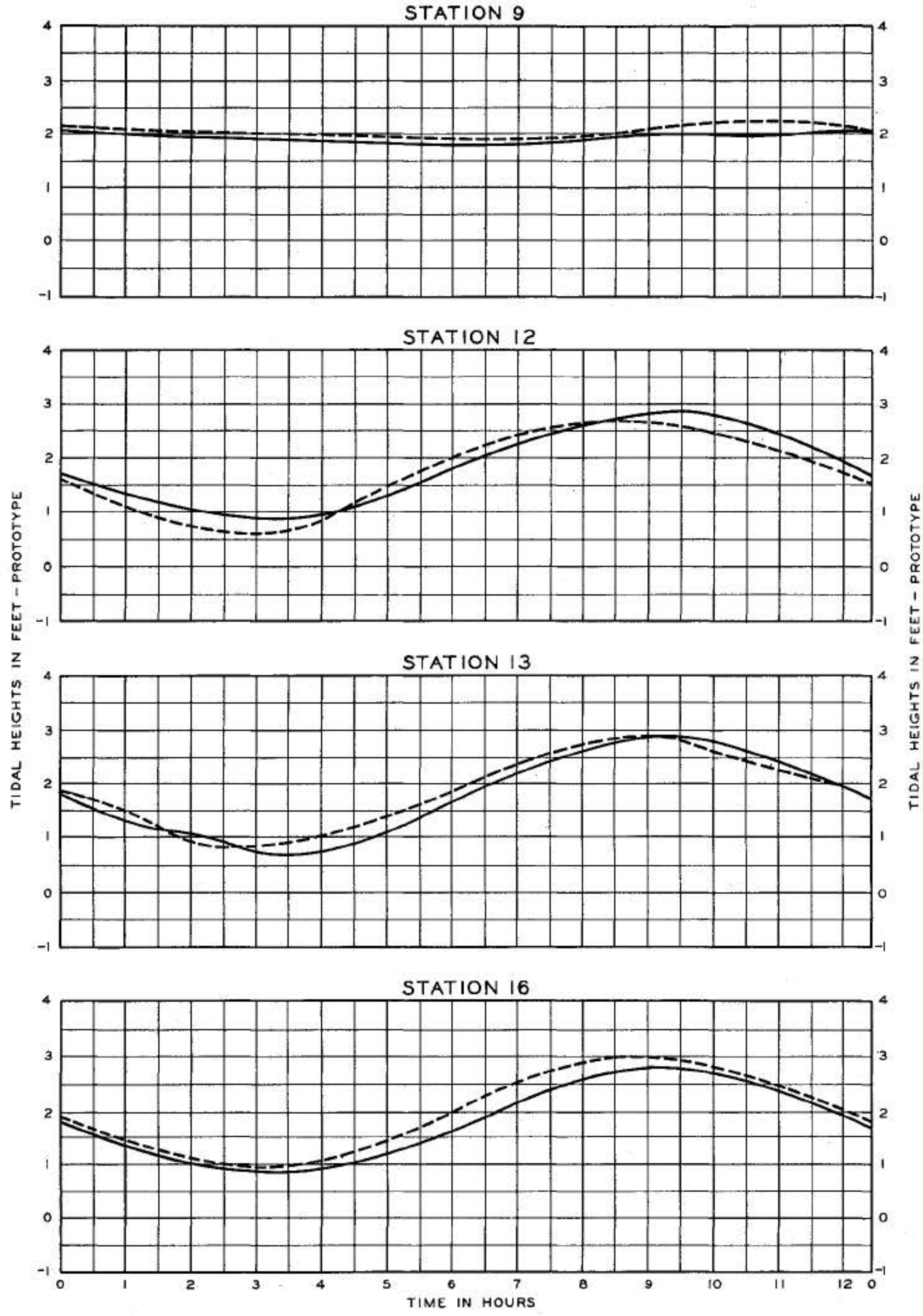
——— PROTOTYPE TIDAL HEIGHTS

- - - - MODEL TIDAL HEIGHTS

NOTE: ELEVATIONS REFER TO MLW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA

TIDE CURVES
VERIFICATION TEST

PLATE 1



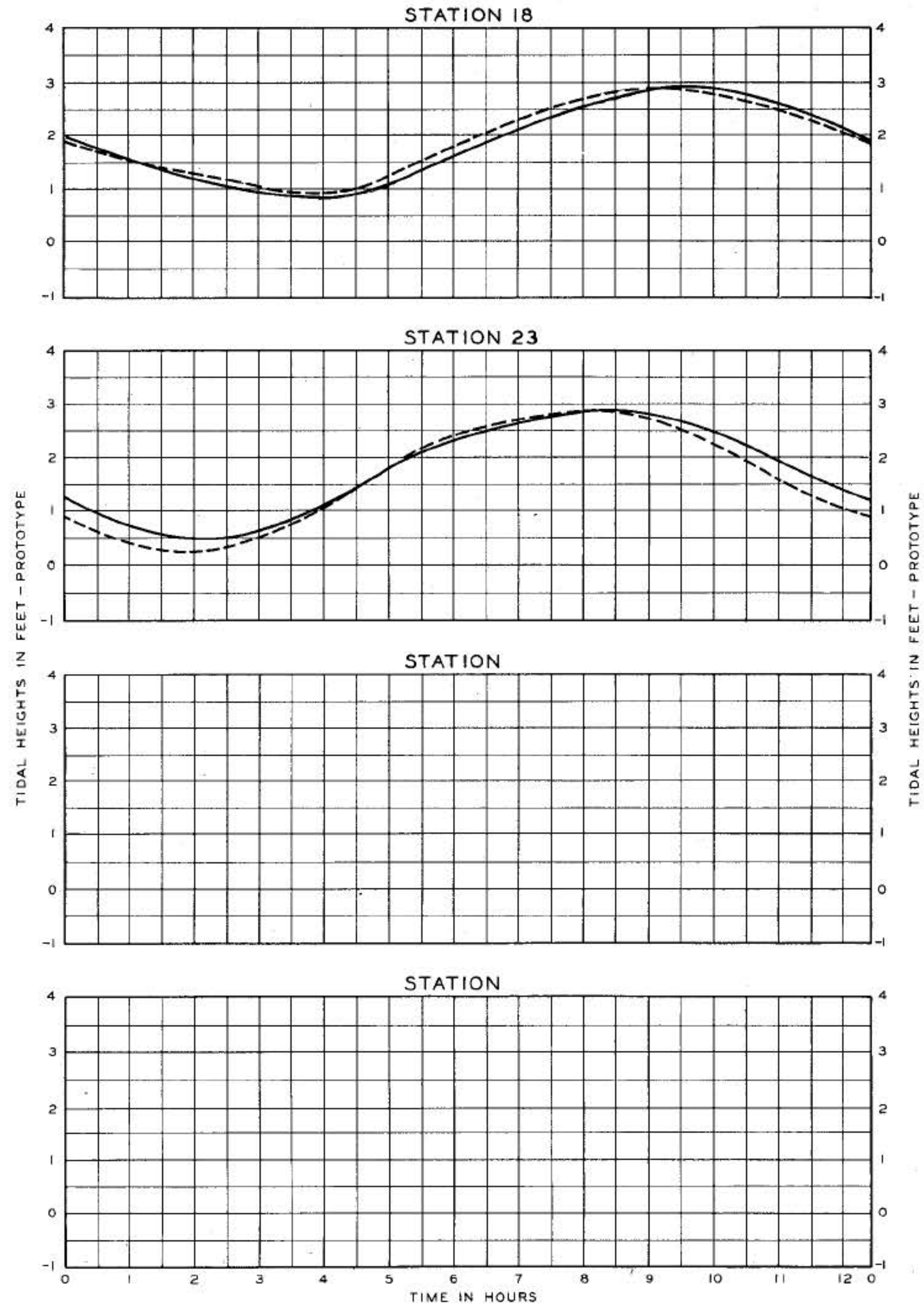
LEGEND

——— PROTOTYPE TIDAL HEIGHTS

– – – – MODEL TIDAL HEIGHTS

NOTE: ELEVATIONS REFER TO MLW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA

TIDE CURVES
VERIFICATION TEST



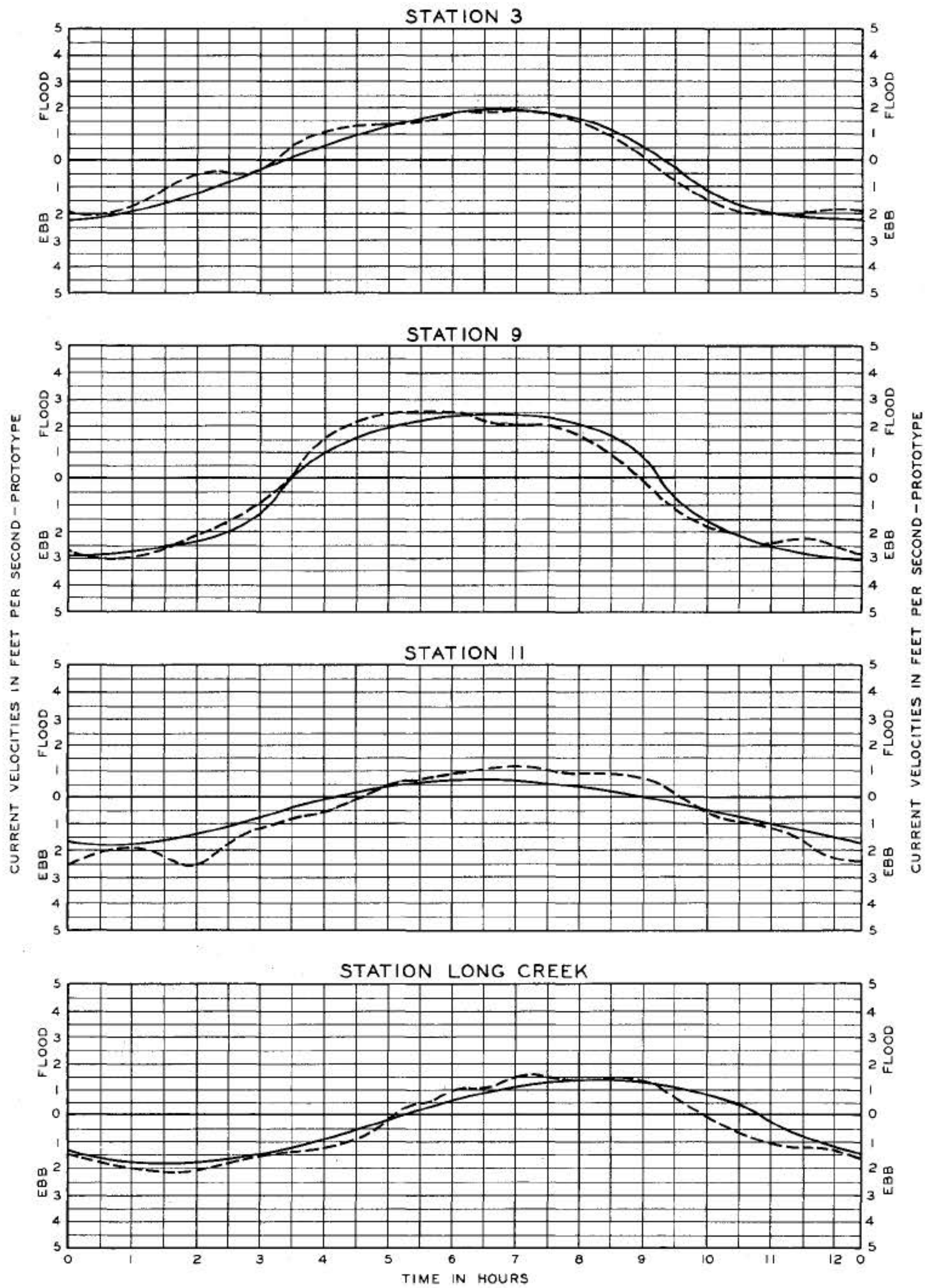
LEGEND

——— PROTOTYPE TIDAL HEIGHTS

- - - - MODEL TIDAL HEIGHTS

NOTE: ELEVATIONS REFER TO MLW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA

TIDE CURVES
VERIFICATION TEST



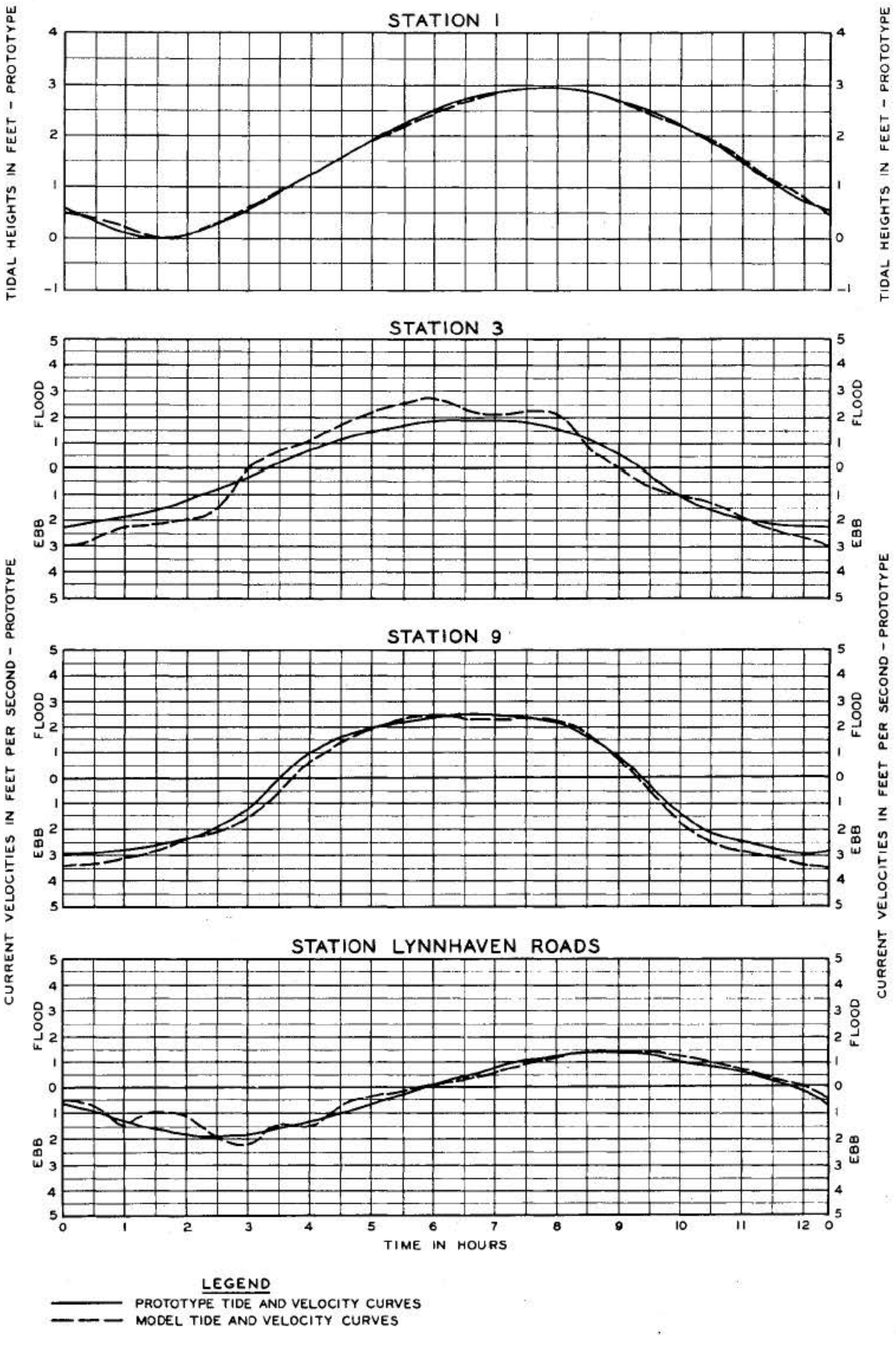
LEGEND

——— PROTOTYPE VELOCITIES

– – – – MODEL VELOCITIES

NOTE: ELEVATIONS REFER TO MLW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA

VELOCITY CURVES VERIFICATION TEST



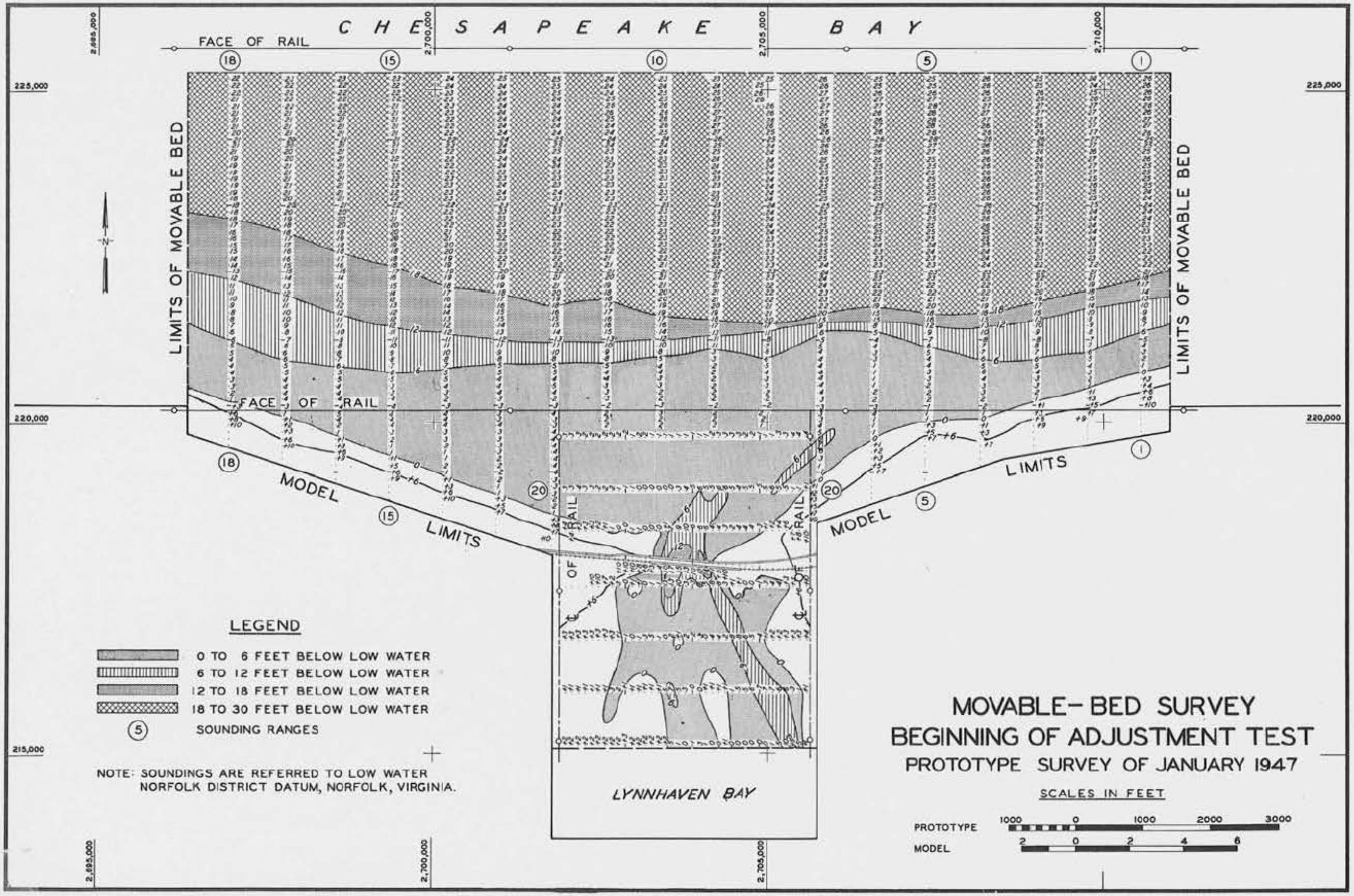
NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

MODEL REPRODUCTION OF PROTOTYPE TIDES AND CURRENTS

SPRING TIDE

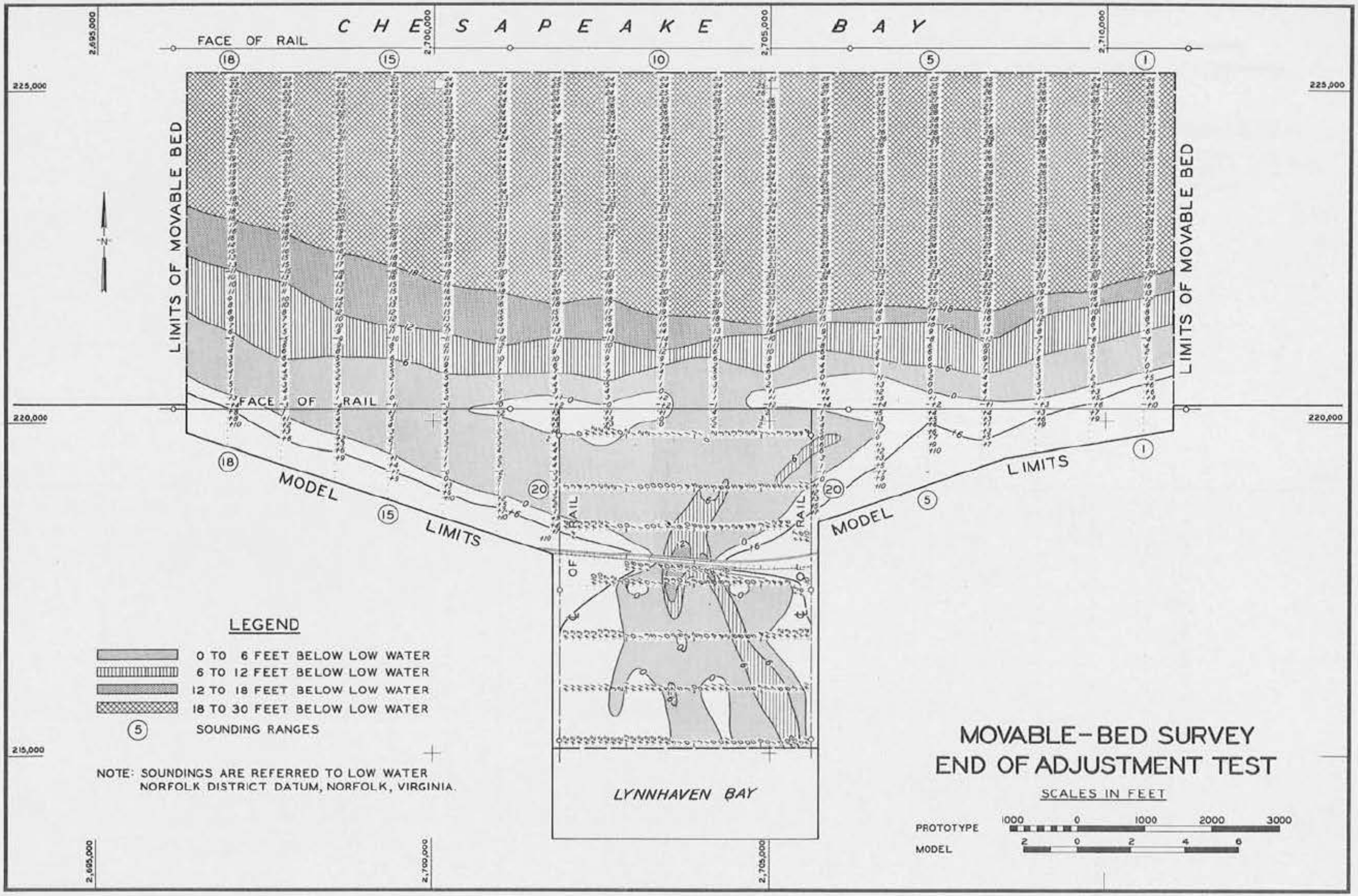
PLATE 5



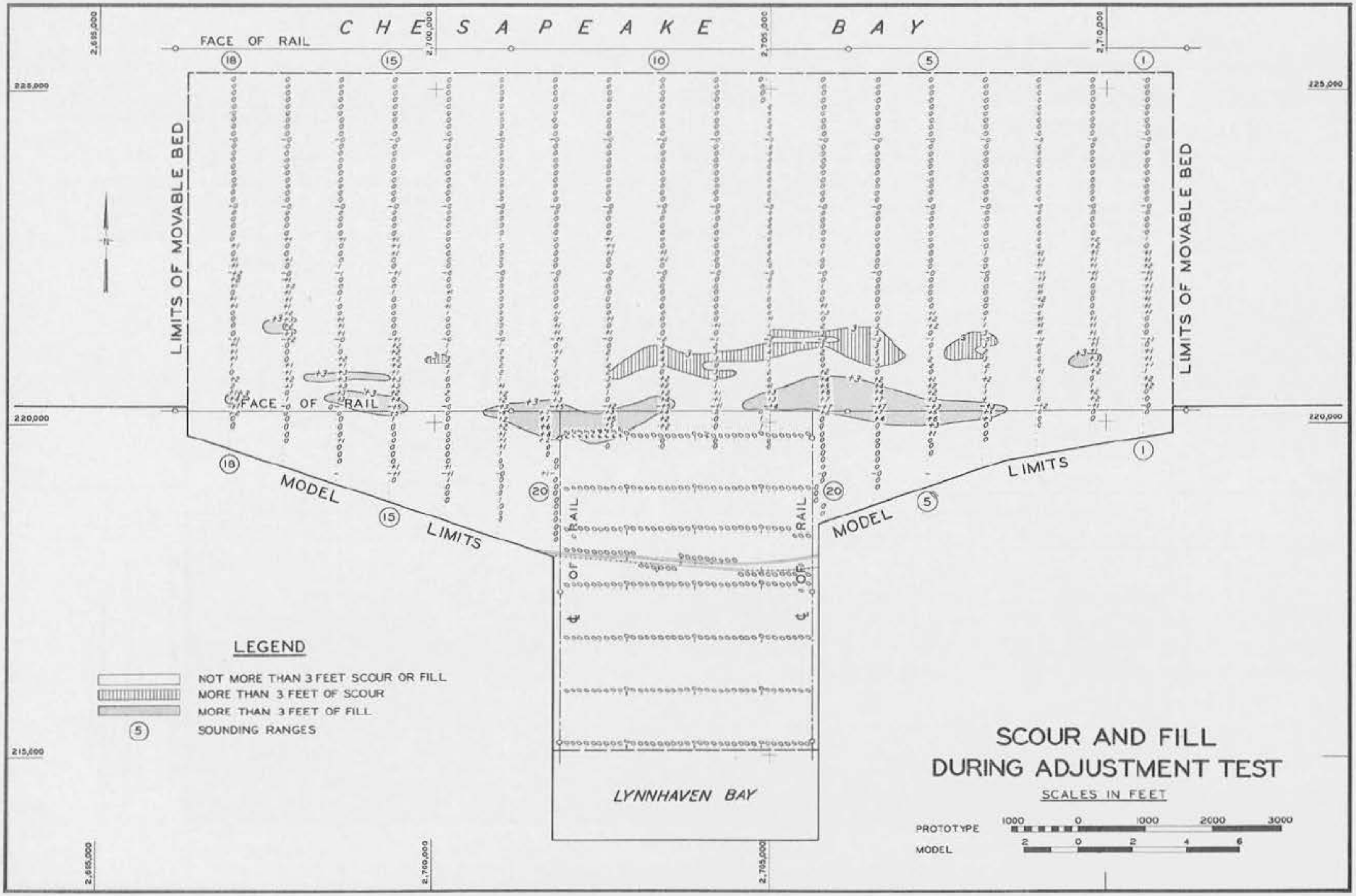
MOVABLE-BED SURVEY
BEGINNING OF ADJUSTMENT TEST
PROTOTYPE SURVEY OF JANUARY 1947

PLATE 6

PLATE 7

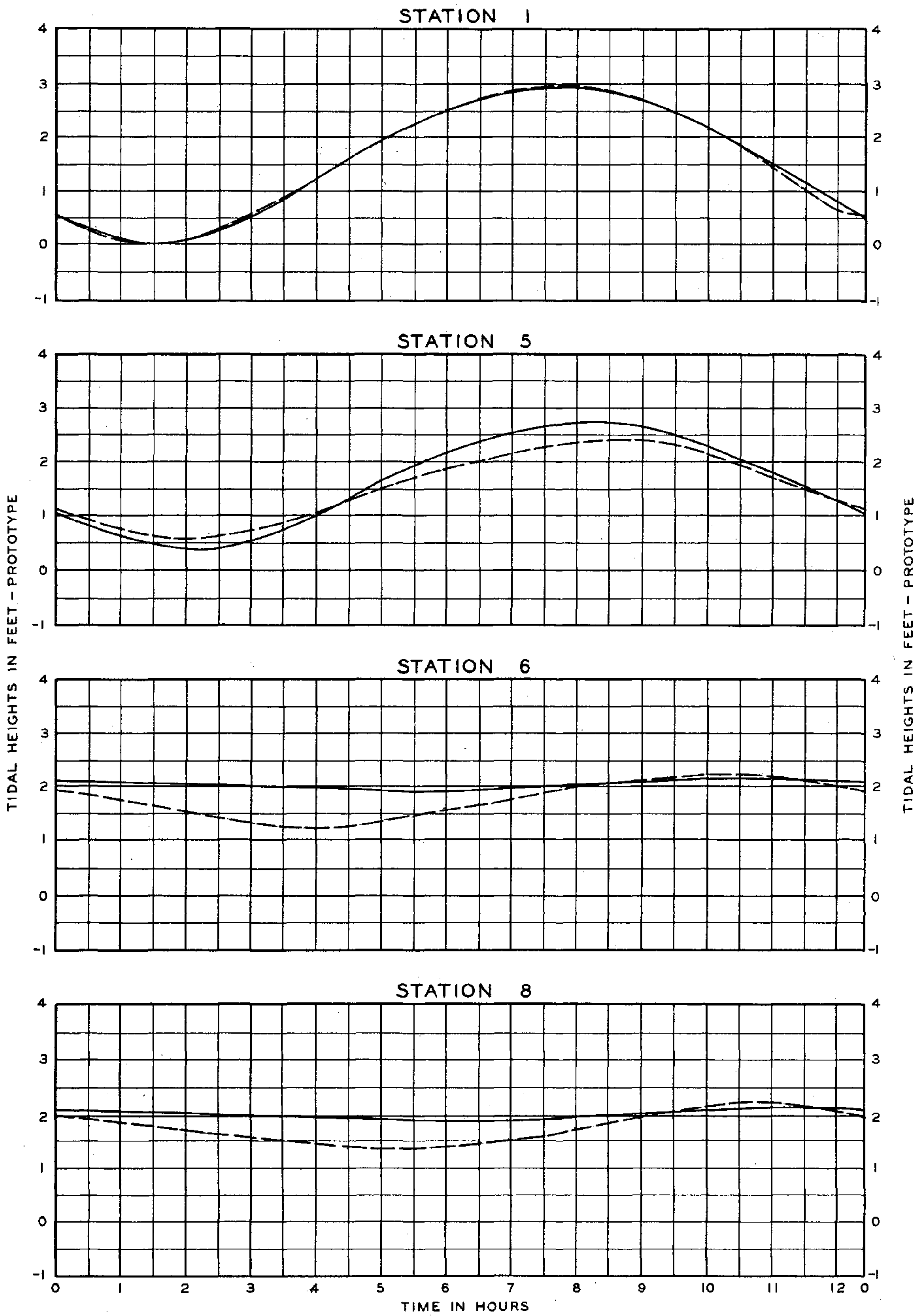


CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
LYNNHAVEN BAY
LEGEND
0 TO 6 FEET BELOW LOW WATER
6 TO 12 FEET BELOW LOW WATER
12 TO 18 FEET BELOW LOW WATER
18 TO 30 FEET BELOW LOW WATER
(5) SOUNDING RANGES
NOTE: SOUNDINGS ARE REFERRED TO LOW WATER NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.
MOVABLE-BED SURVEY
END OF ADJUSTMENT TEST
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000 3000
MODEL 2 0 2 4 6



SCOUR AND FILL DURING ADJUSTMENT TEST

PLATE 8



LEGEND

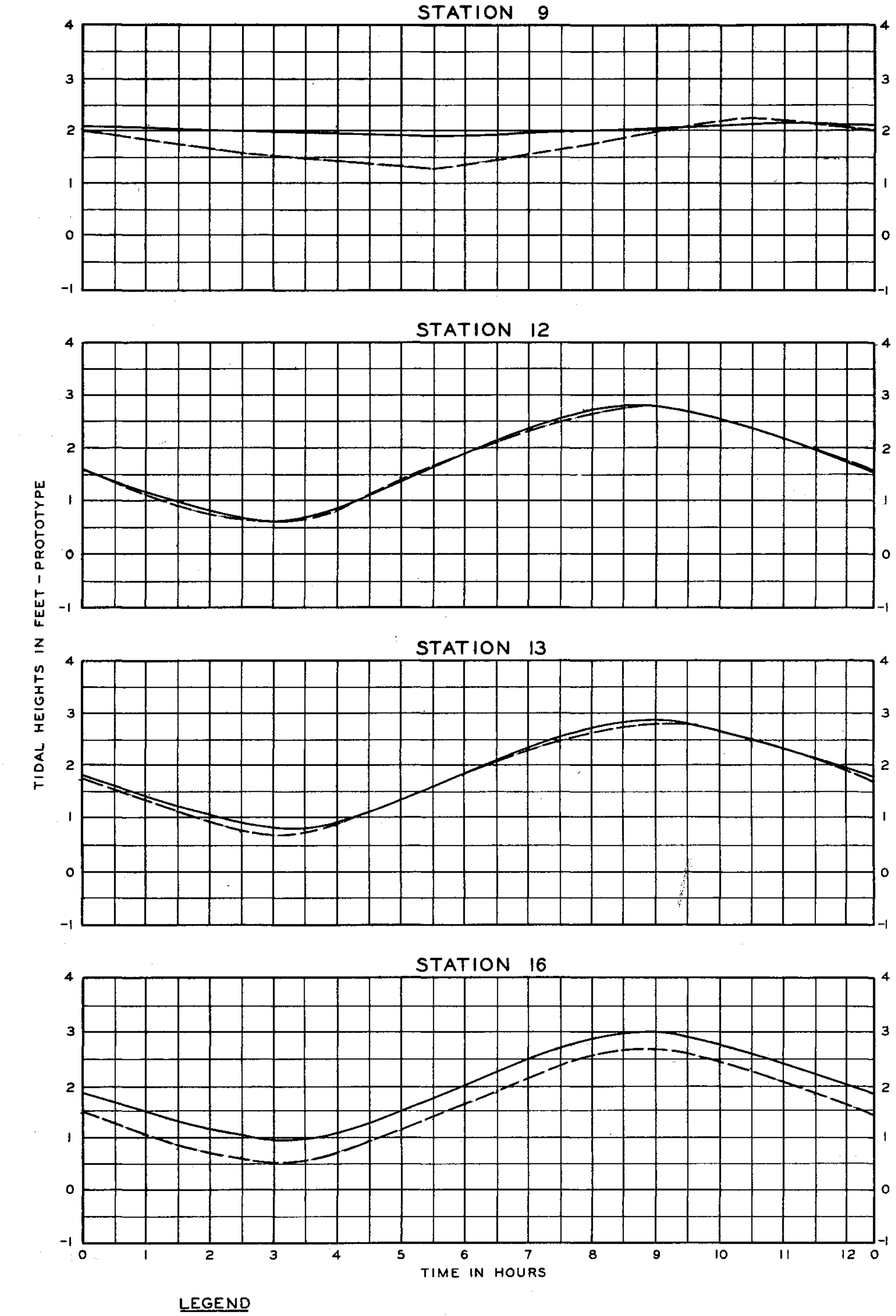
——— BASE TEST TIDAL HEIGHTS.

– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

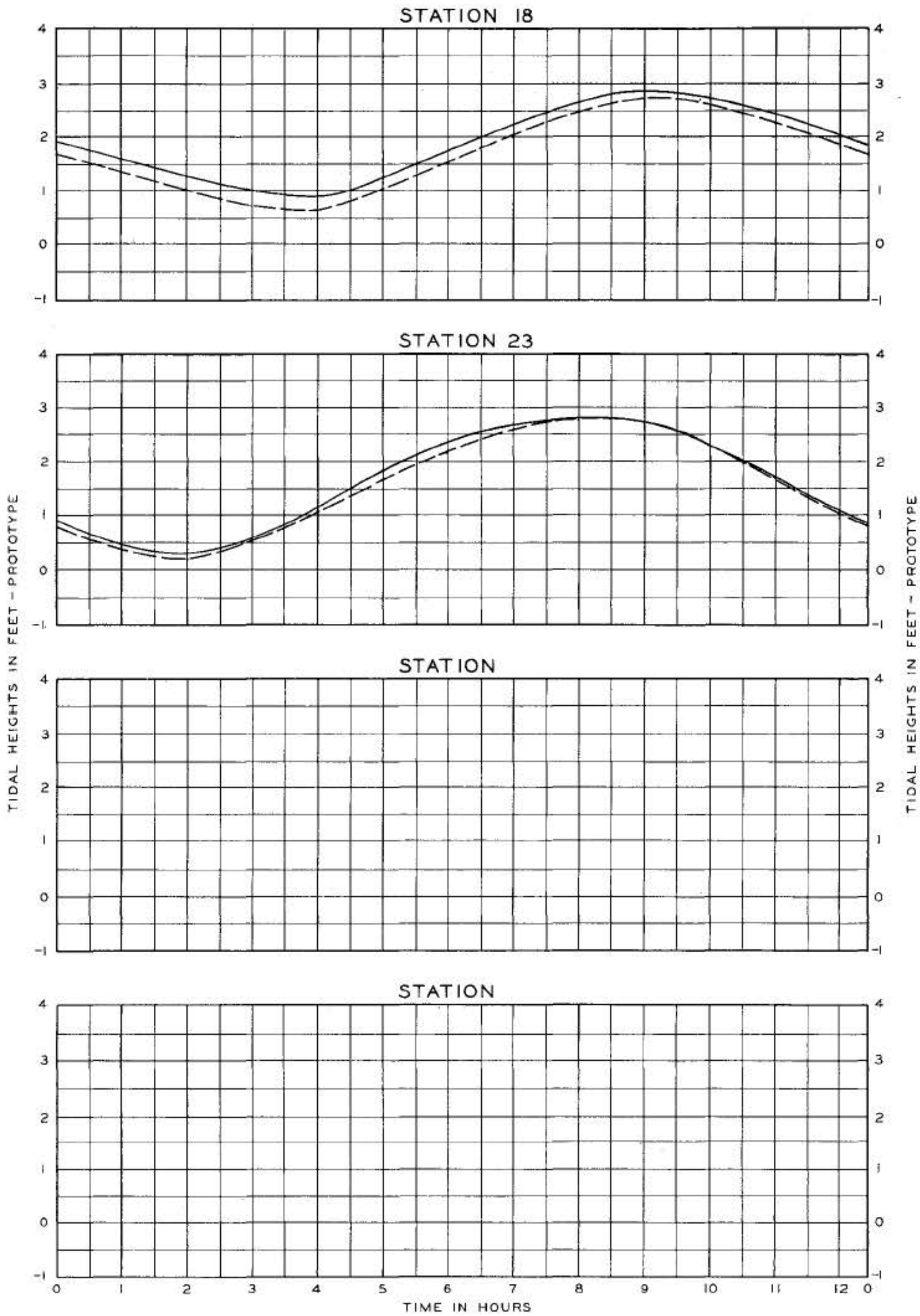
TIDE CURVES
PLAN 1
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 1
SPRING TIDE



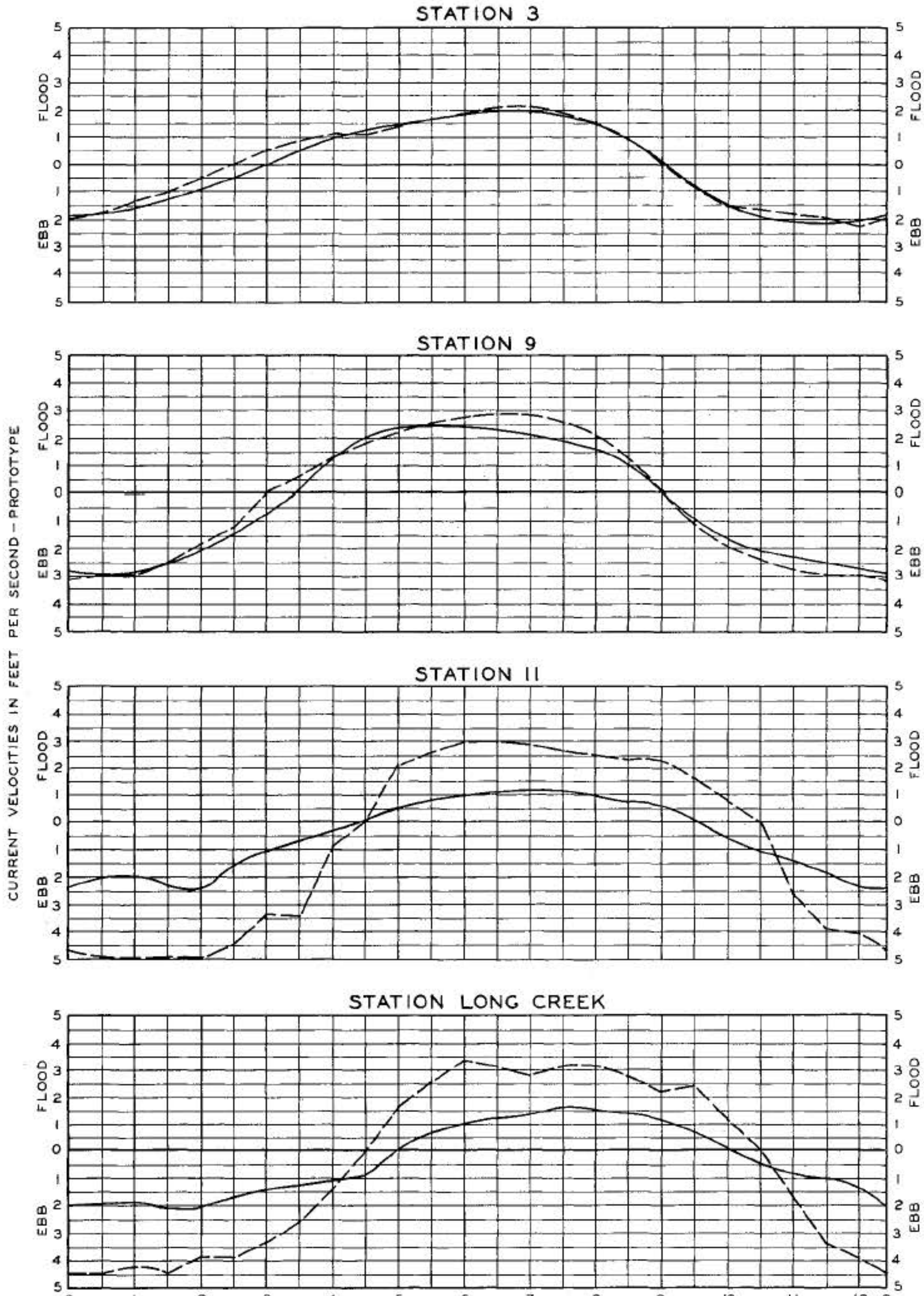
LEGEND

——— BASE TEST TIDAL HEIGHTS
– – – – PLAN TEST TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

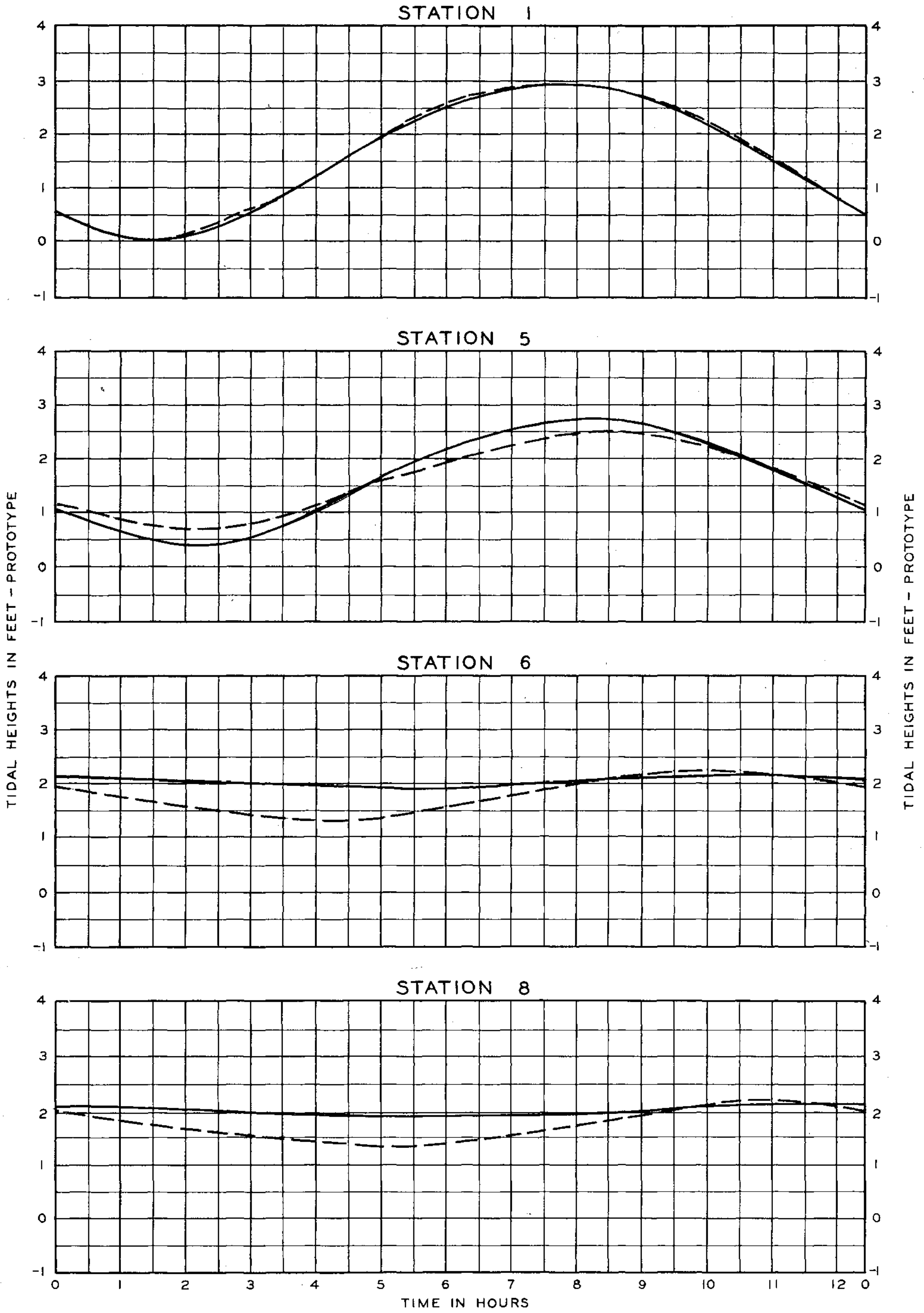
ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN I
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

VELOCITY CURVES
PLAN I
SPRING TIDE



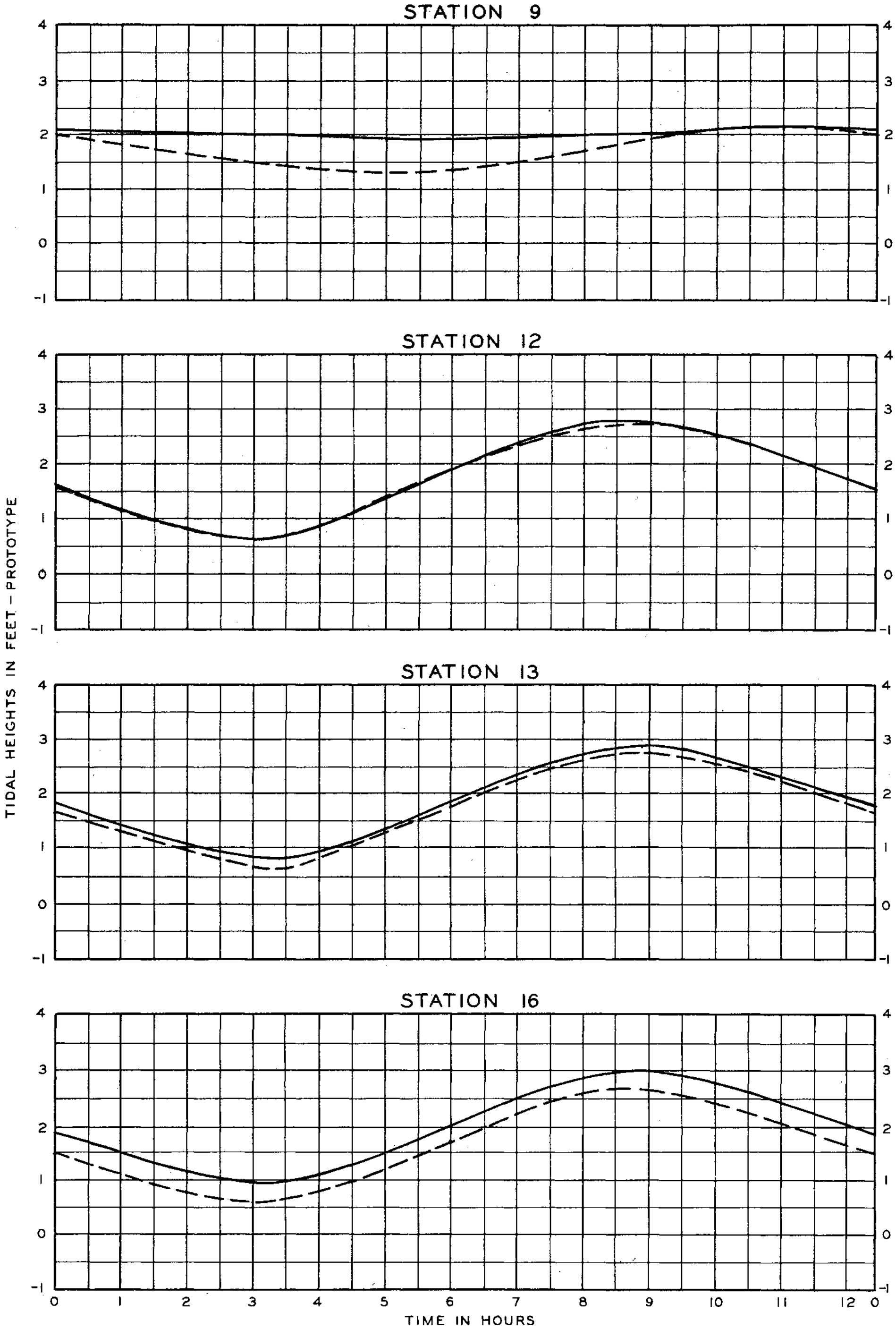
LEGEND

——— BASE TEST TIDAL HEIGHTS.
– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 2
SPRING TIDE



LEGEND

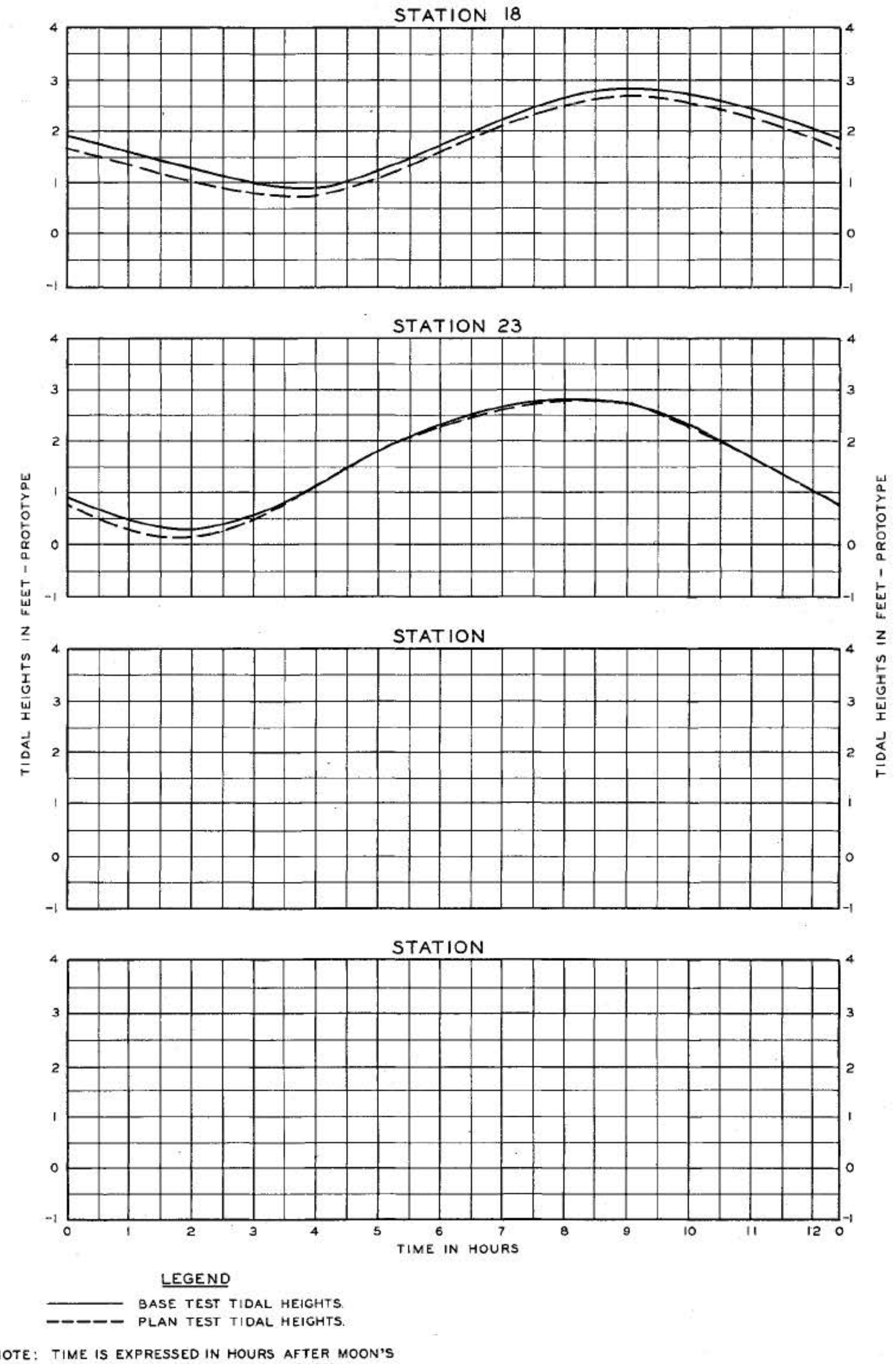
——— BASE TEST TIDAL HEIGHTS.

– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

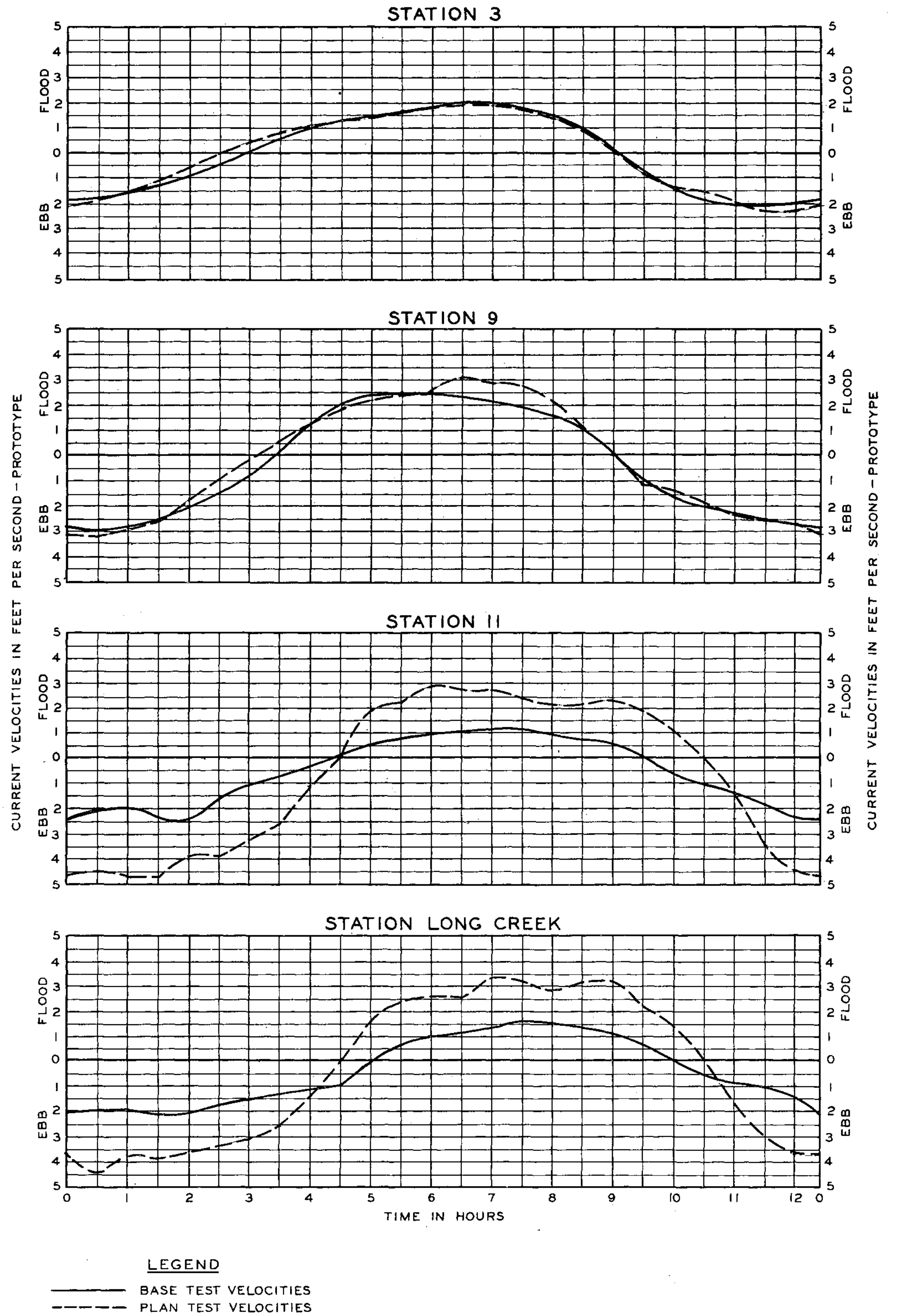
TIDE CURVES
PLAN 2
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

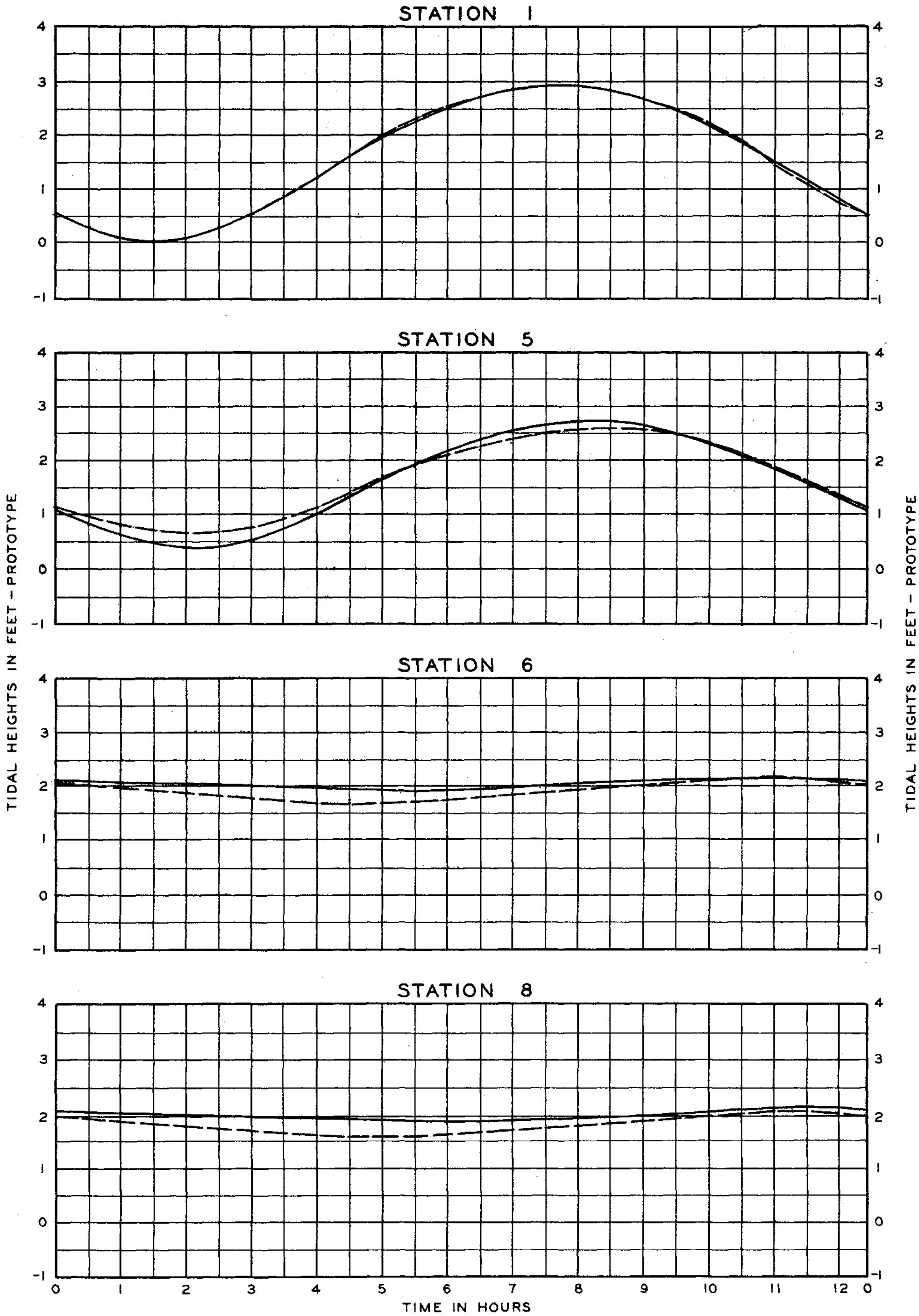
ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 2
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

VELOCITY CURVES
PLAN 2
SPRING TIDE



LEGEND

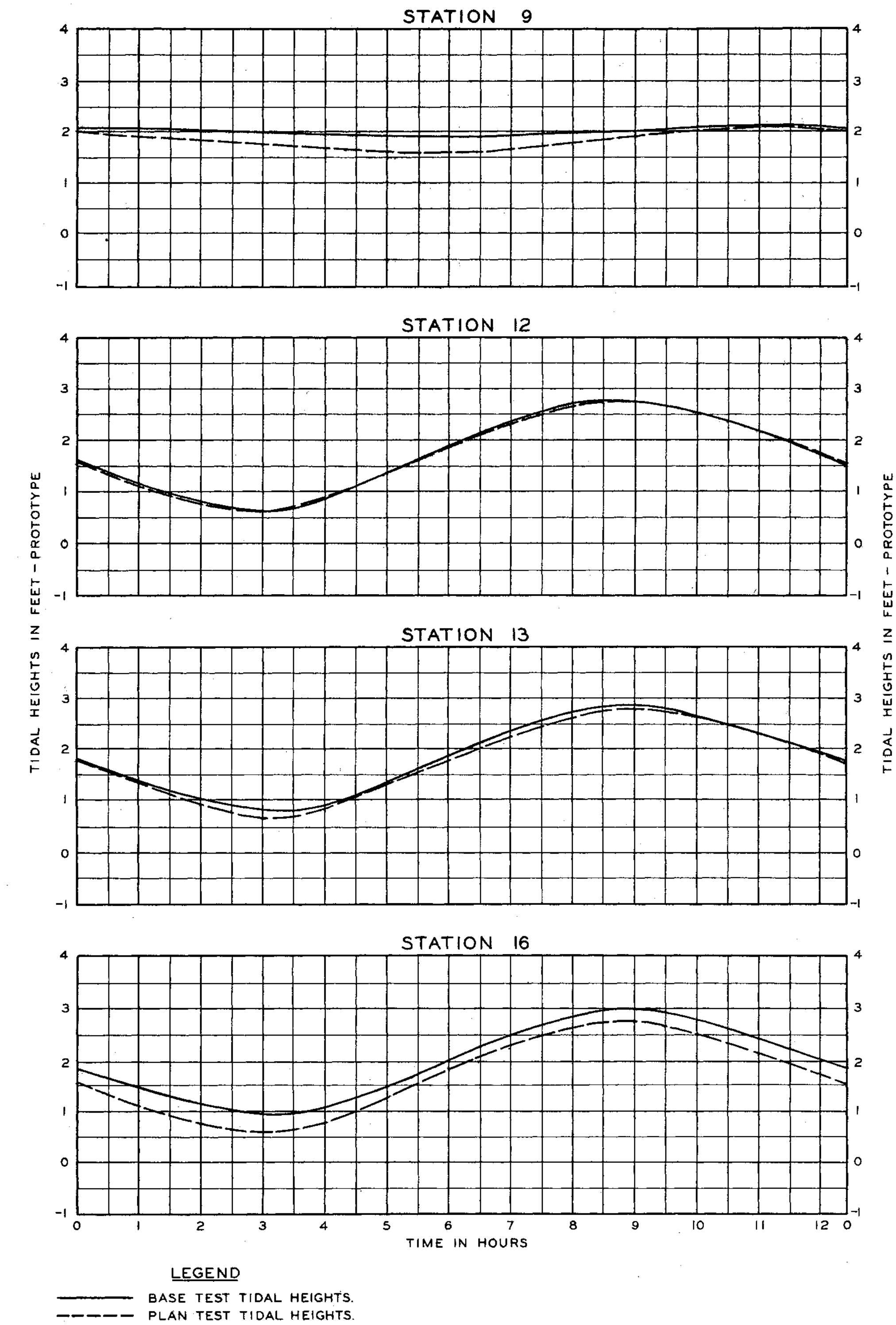
——— BASE TEST TIDAL HEIGHTS.

– – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

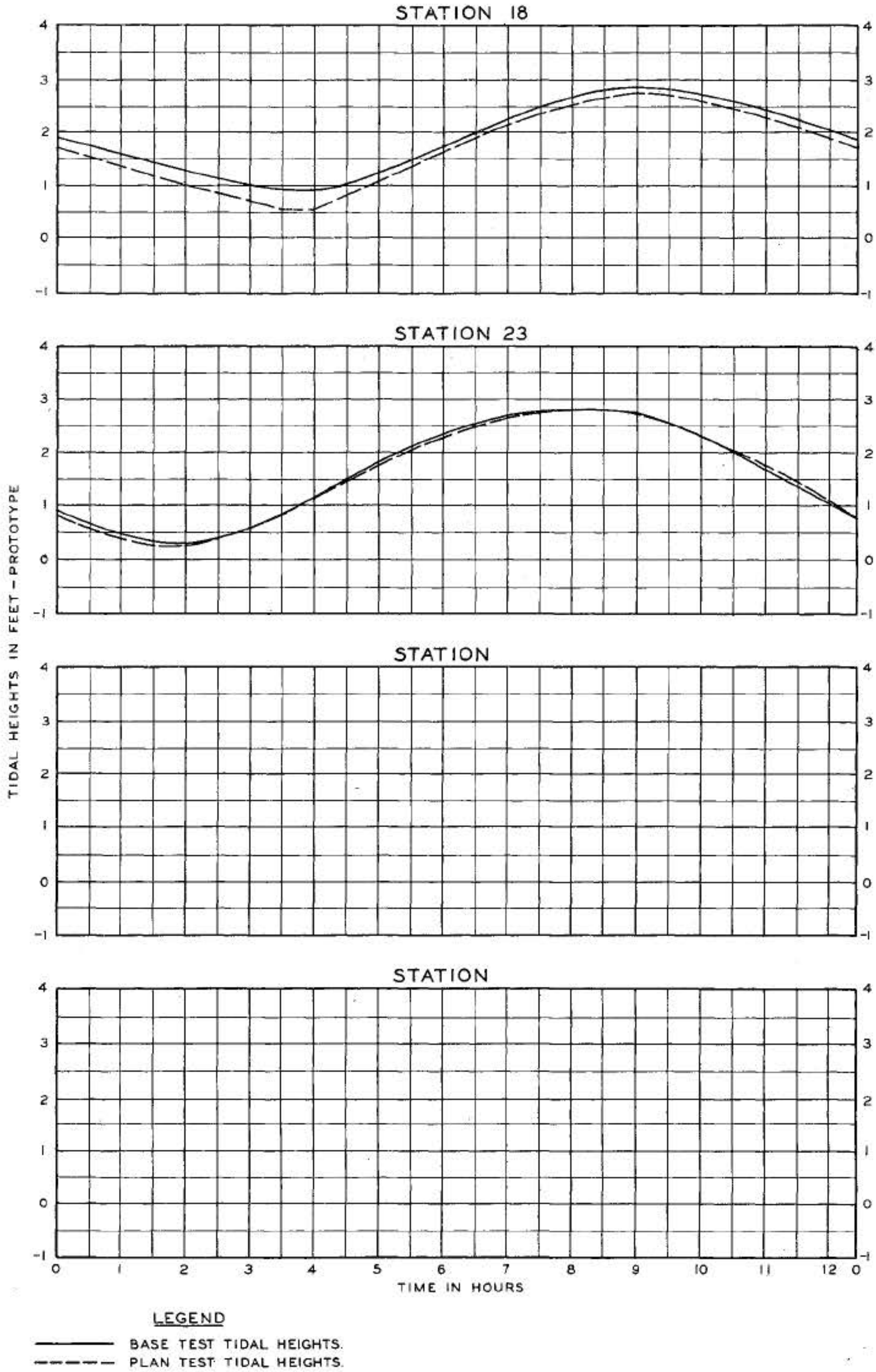
TIDE CURVES
PLAN 3
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

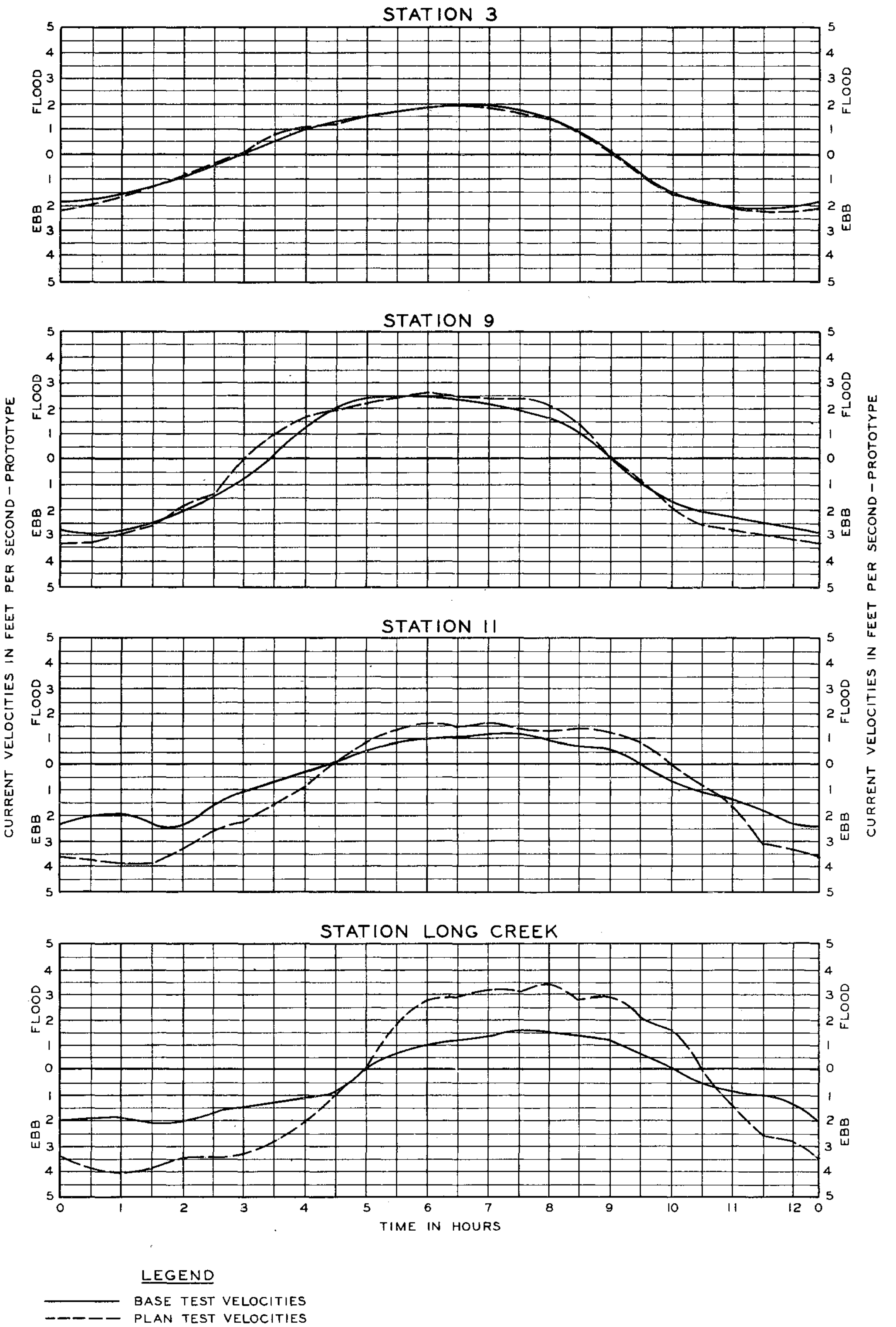
TIDE CURVES
PLAN 3
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

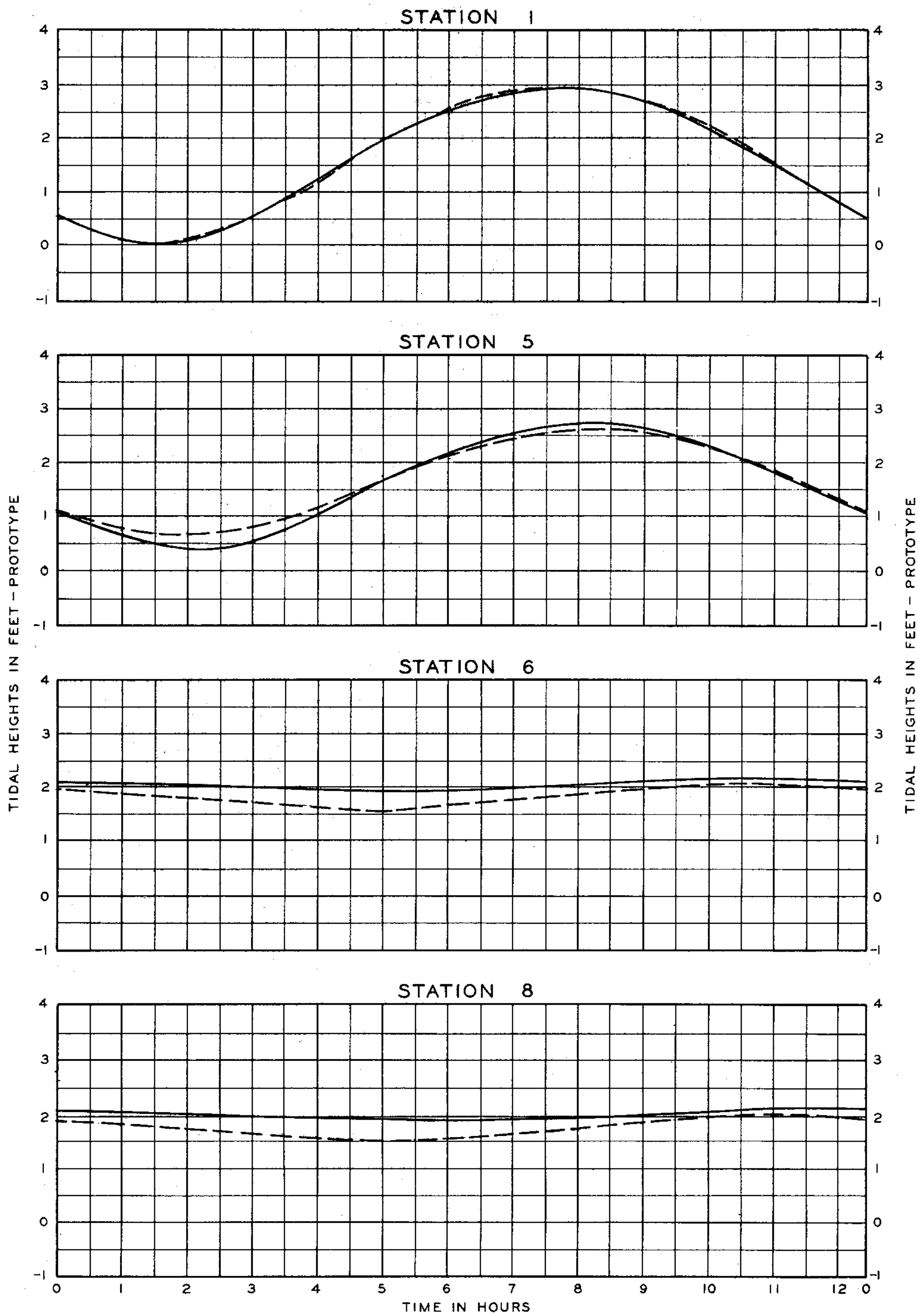
ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 3
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

VELOCITY CURVES
PLAN 3
SPRING TIDE



LEGEND

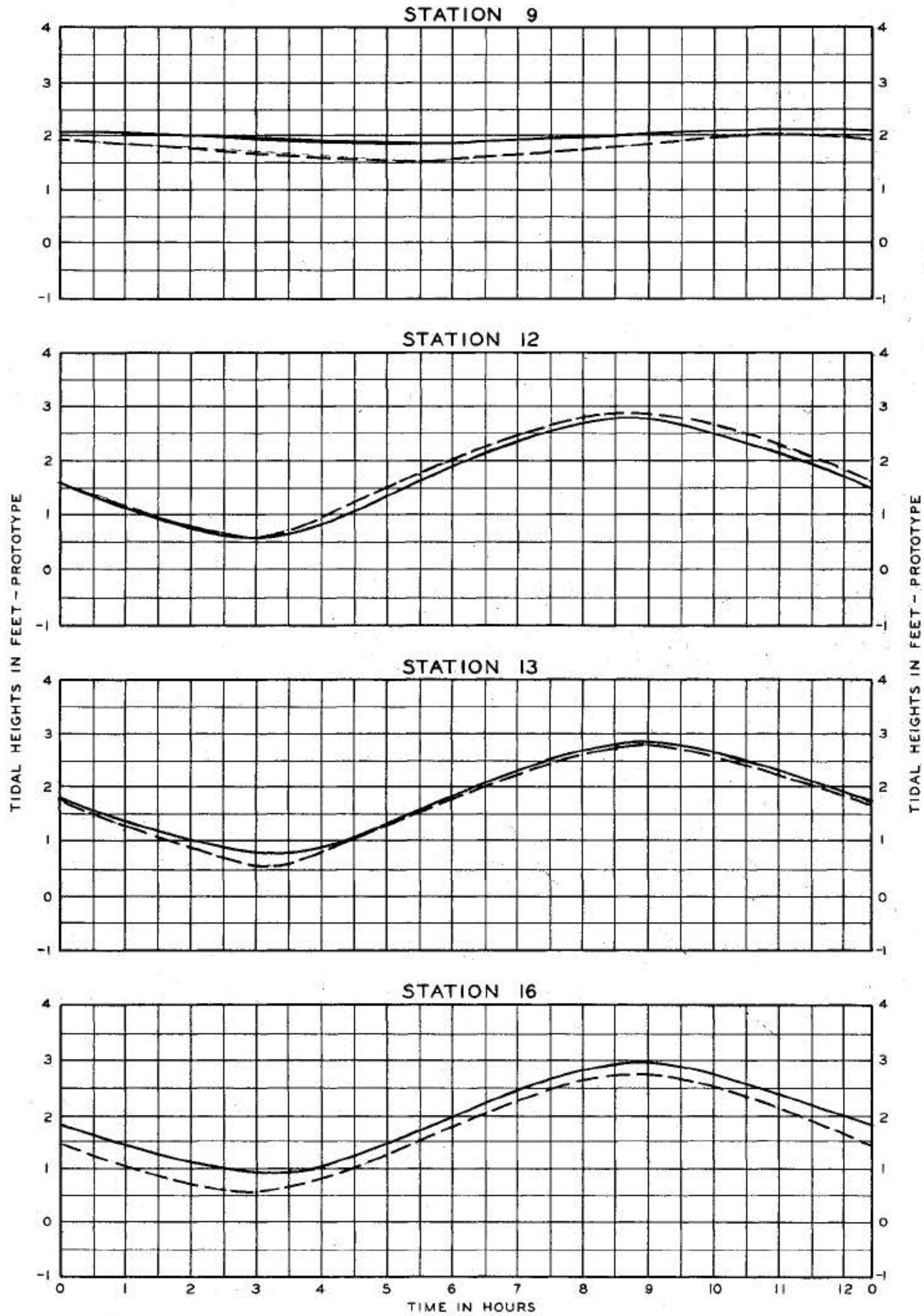
——— BASE TEST TIDAL HEIGHTS.

– – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 4
SPRING TIDE



LEGEND

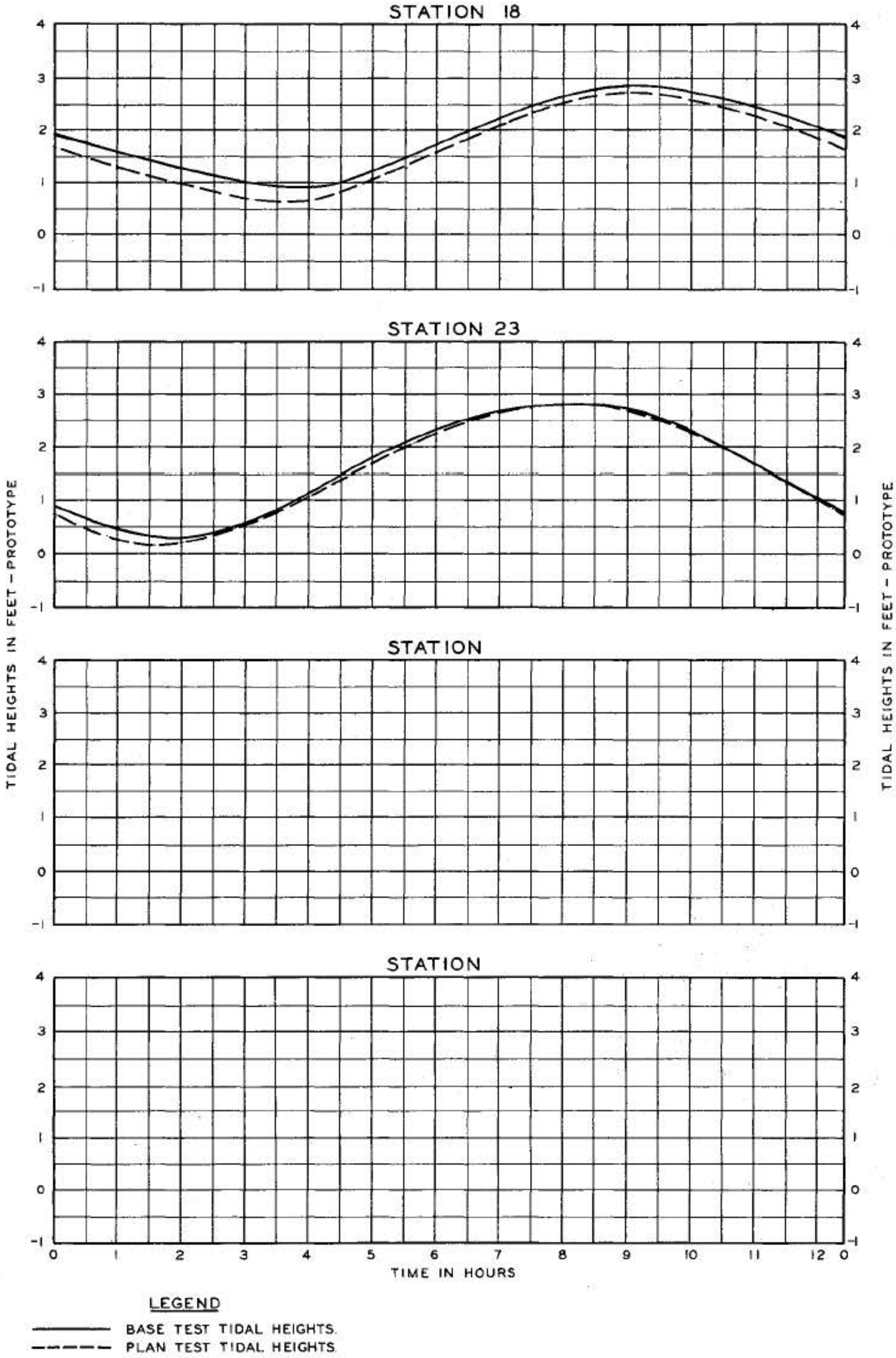
——— BASE TEST TIDAL HEIGHTS.

– – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 4
SPRING TIDE

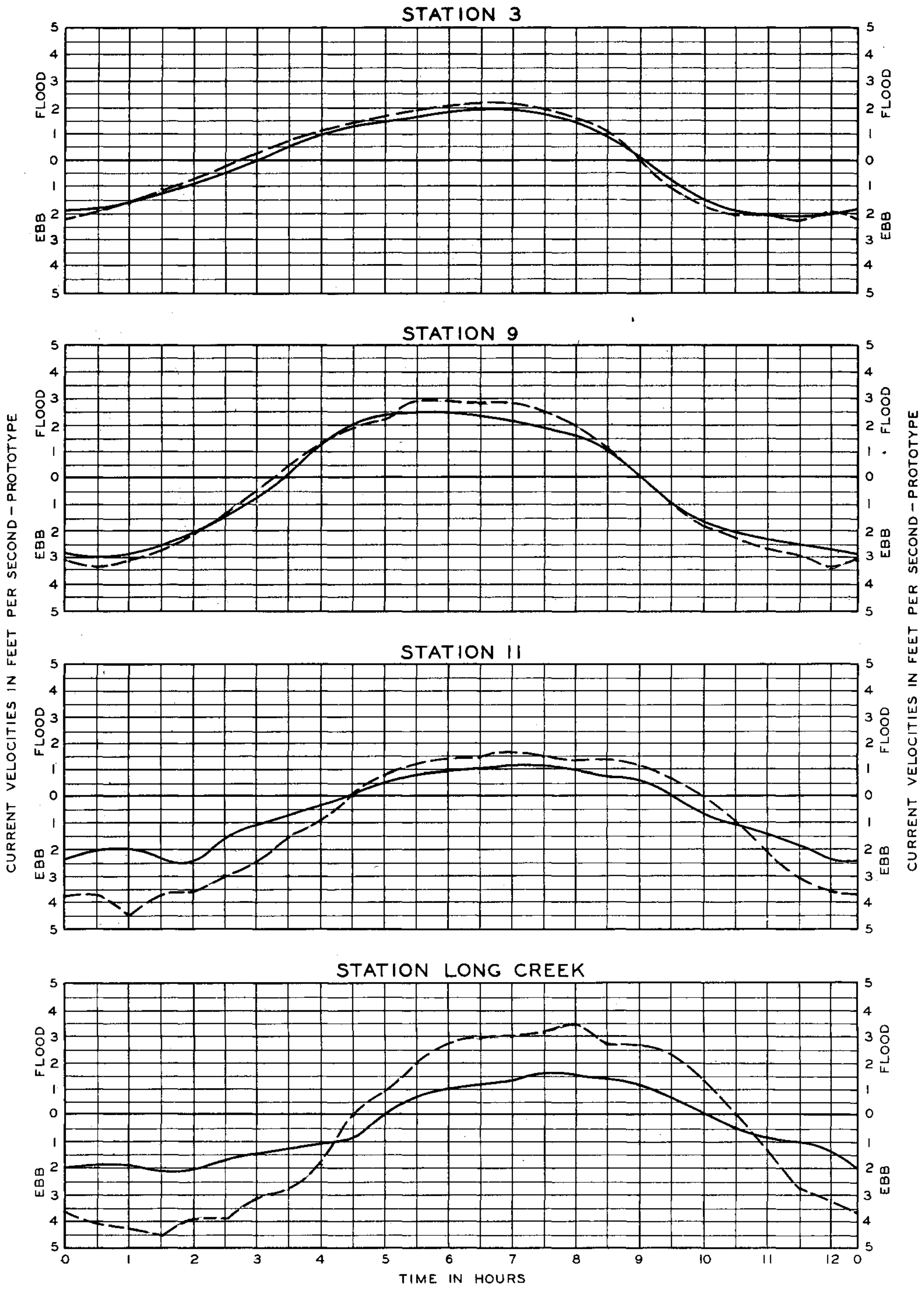


NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 4
SPRING TIDE

PLATE 23

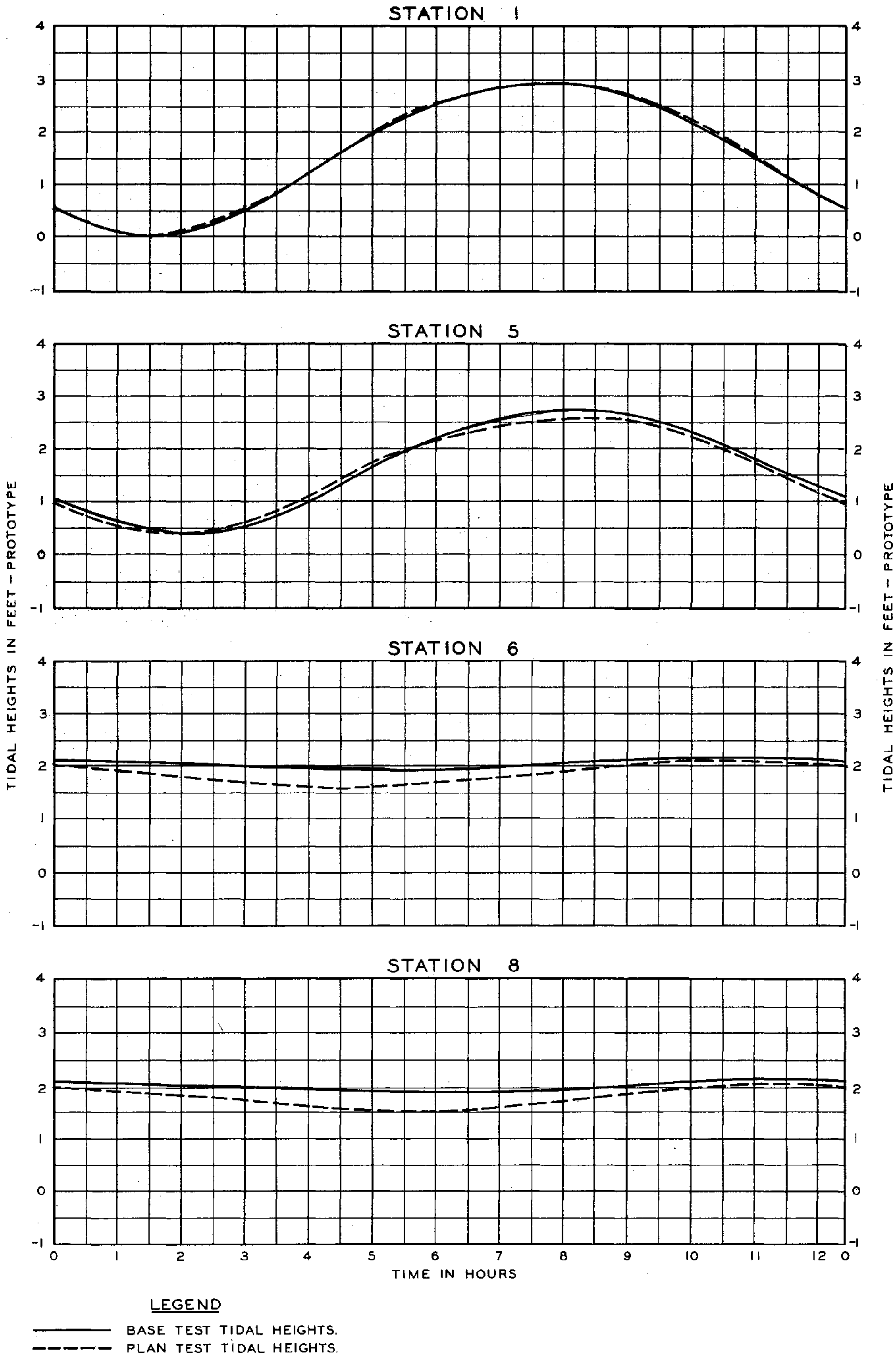


LEGEND

——— BASE TEST VELOCITIES
- - - - PLAN TEST VELOCITIES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

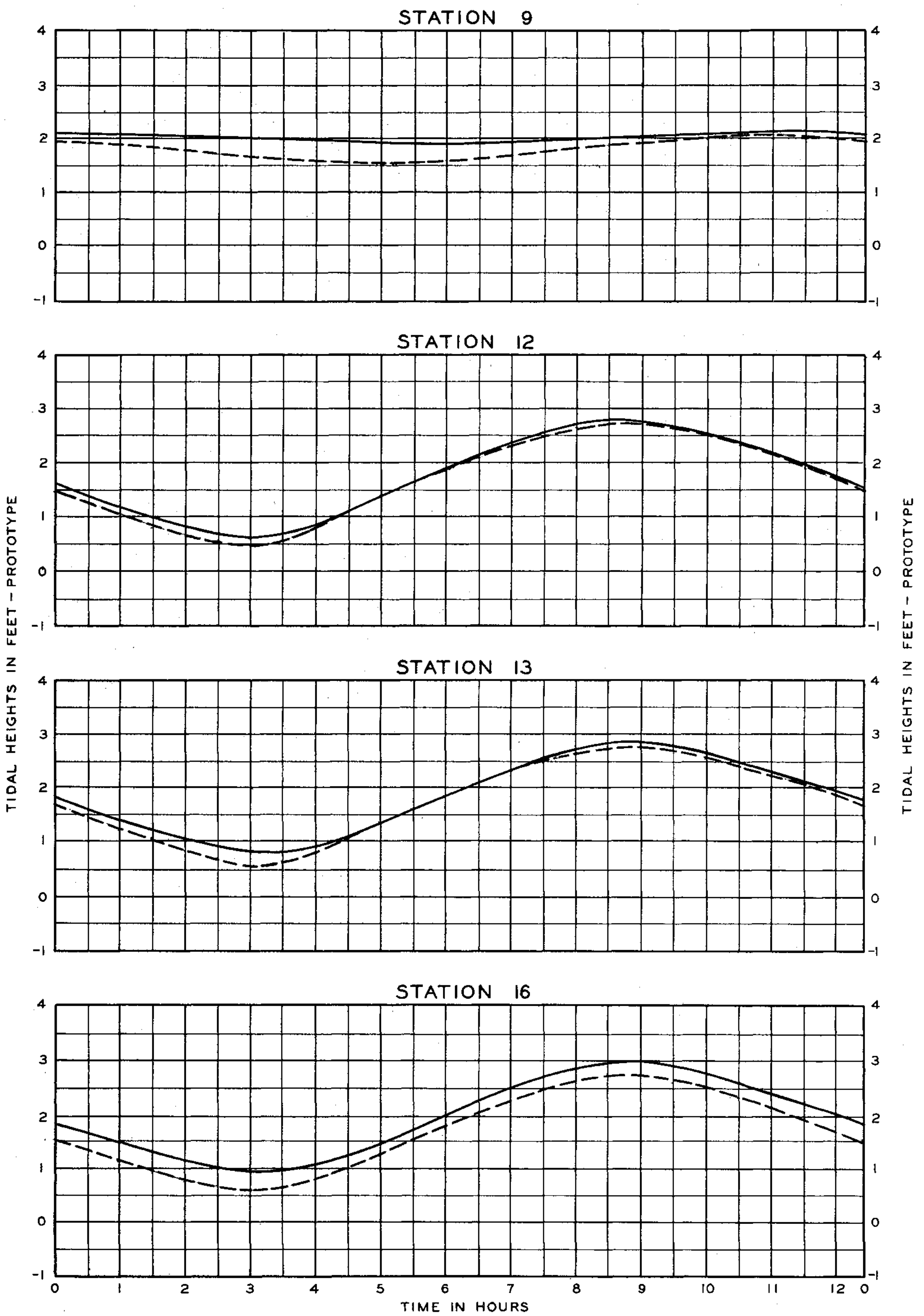
VELOCITY CURVES
PLAN 4
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 5
SPRING TIDE



LEGEND

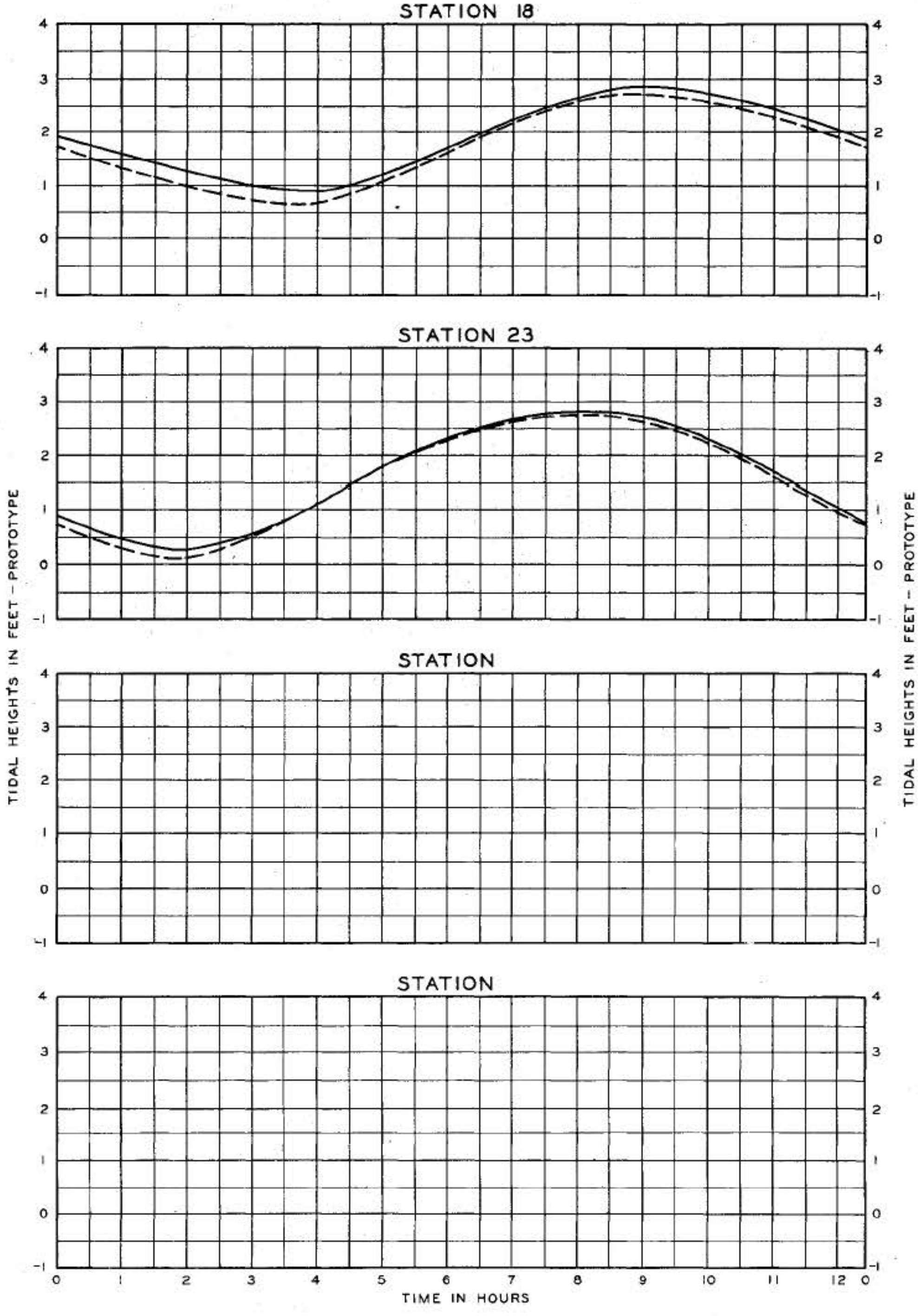
——— BASE TEST TIDAL HEIGHTS.

– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 5
SPRING TIDE



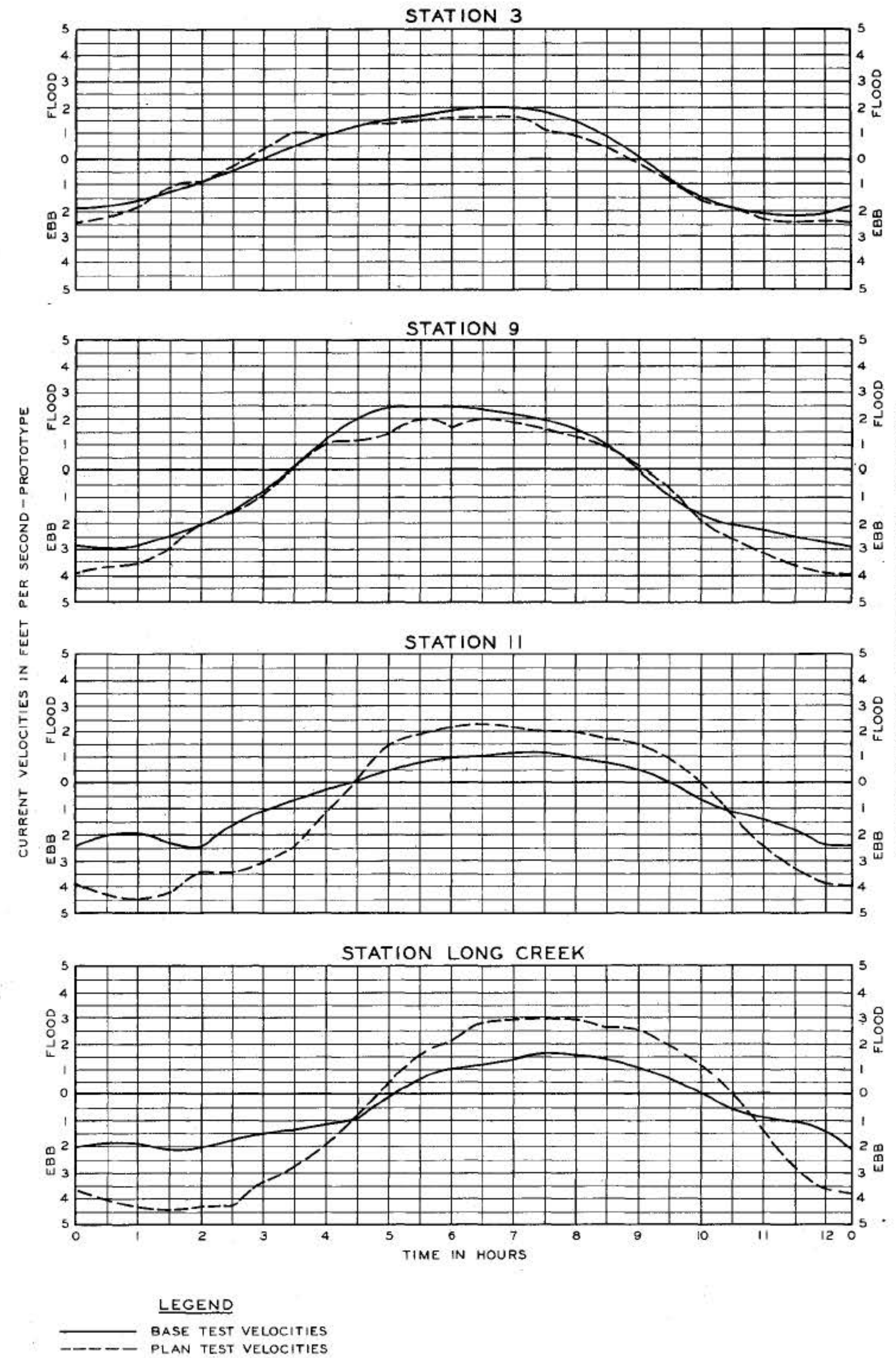
LEGEND

——— BASE TEST TIDAL HEIGHTS.
– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

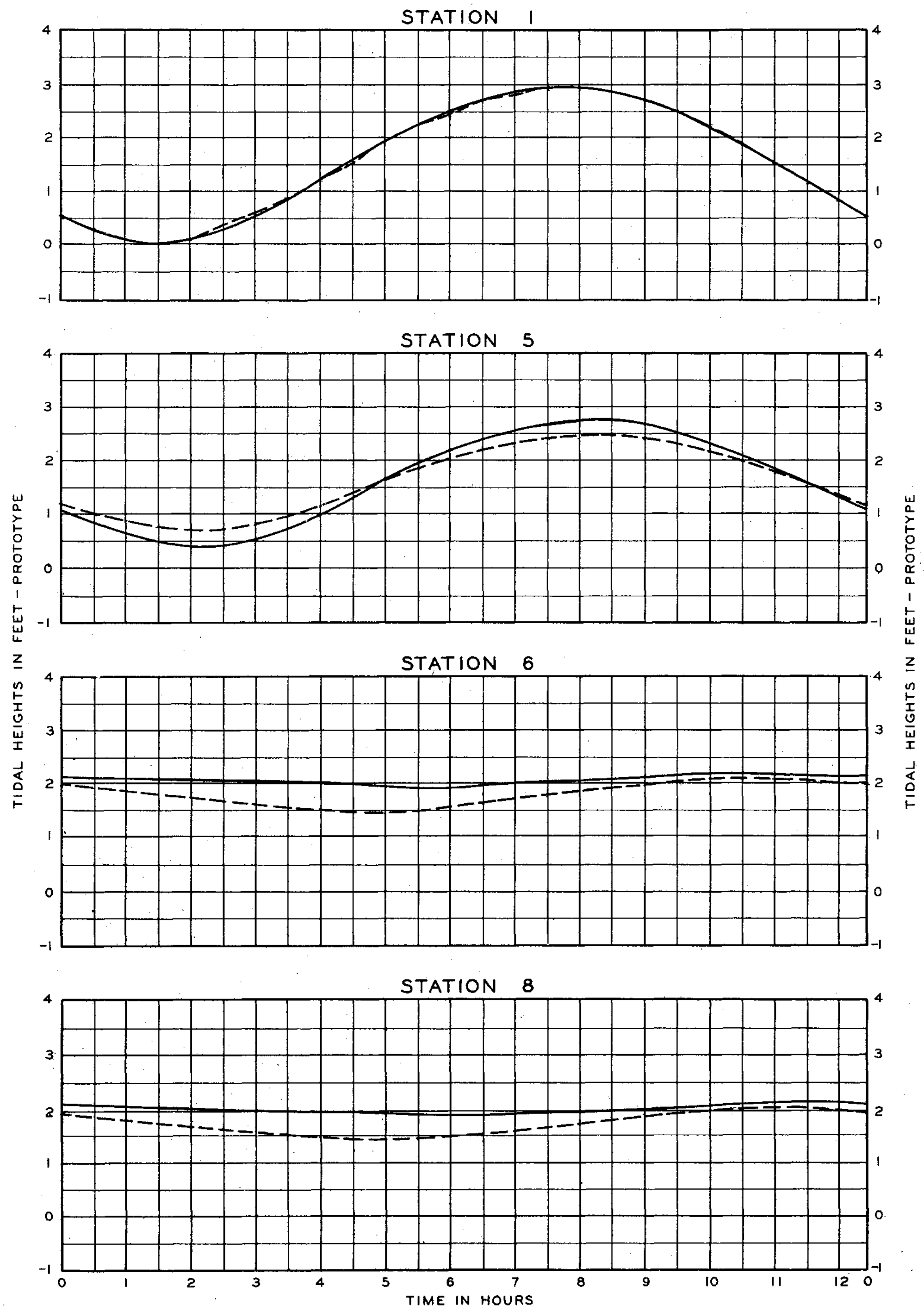
ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 5
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

VELOCITY CURVES
PLAN 5
SPRING TIDE



LEGEND

———— BASE TEST TIDAL HEIGHTS.

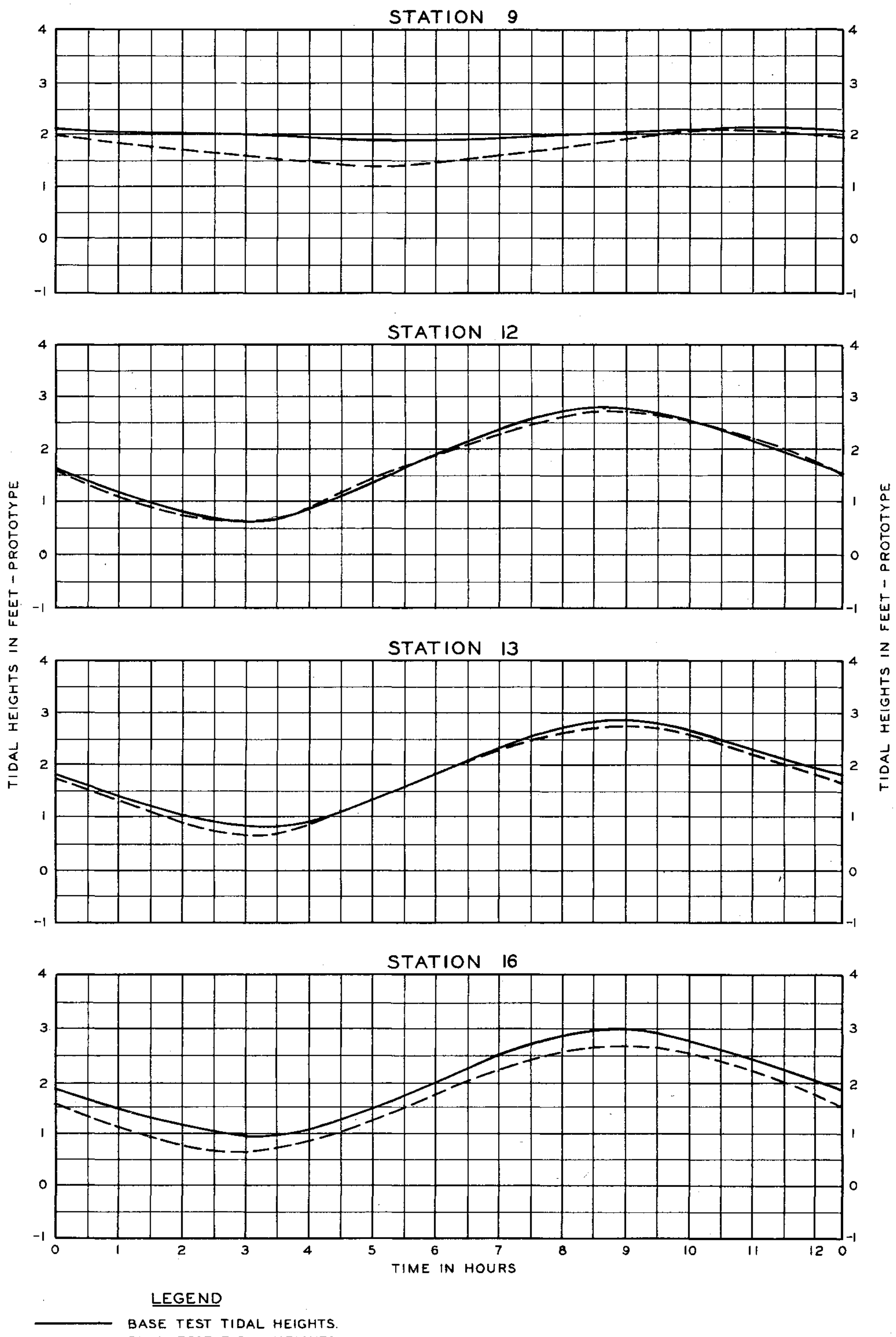
– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 6
SPRING TIDE

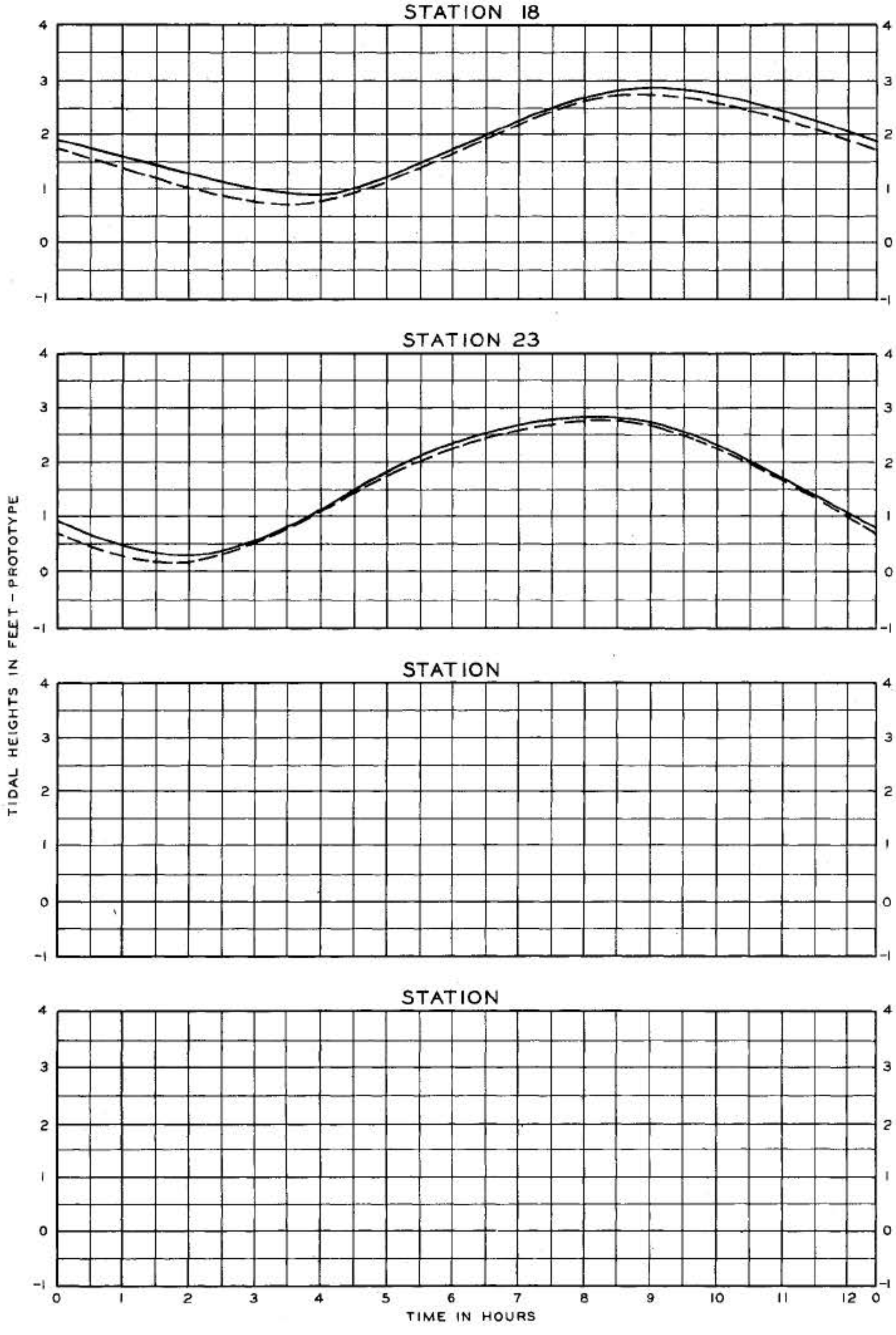
PLATE 29



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 6
SPRING TIDE



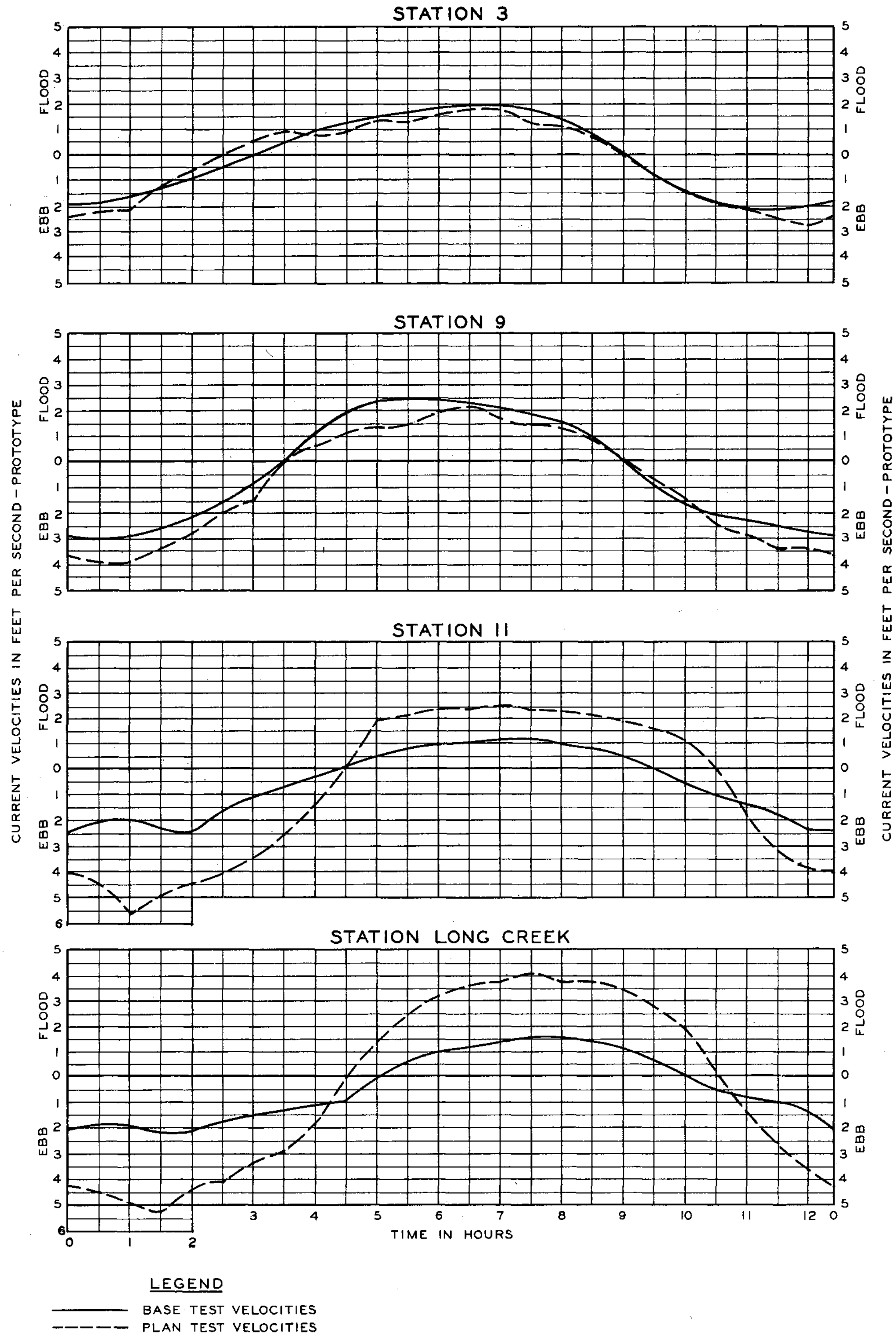
LEGEND

——— BASE TEST TIDAL HEIGHTS.
– – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

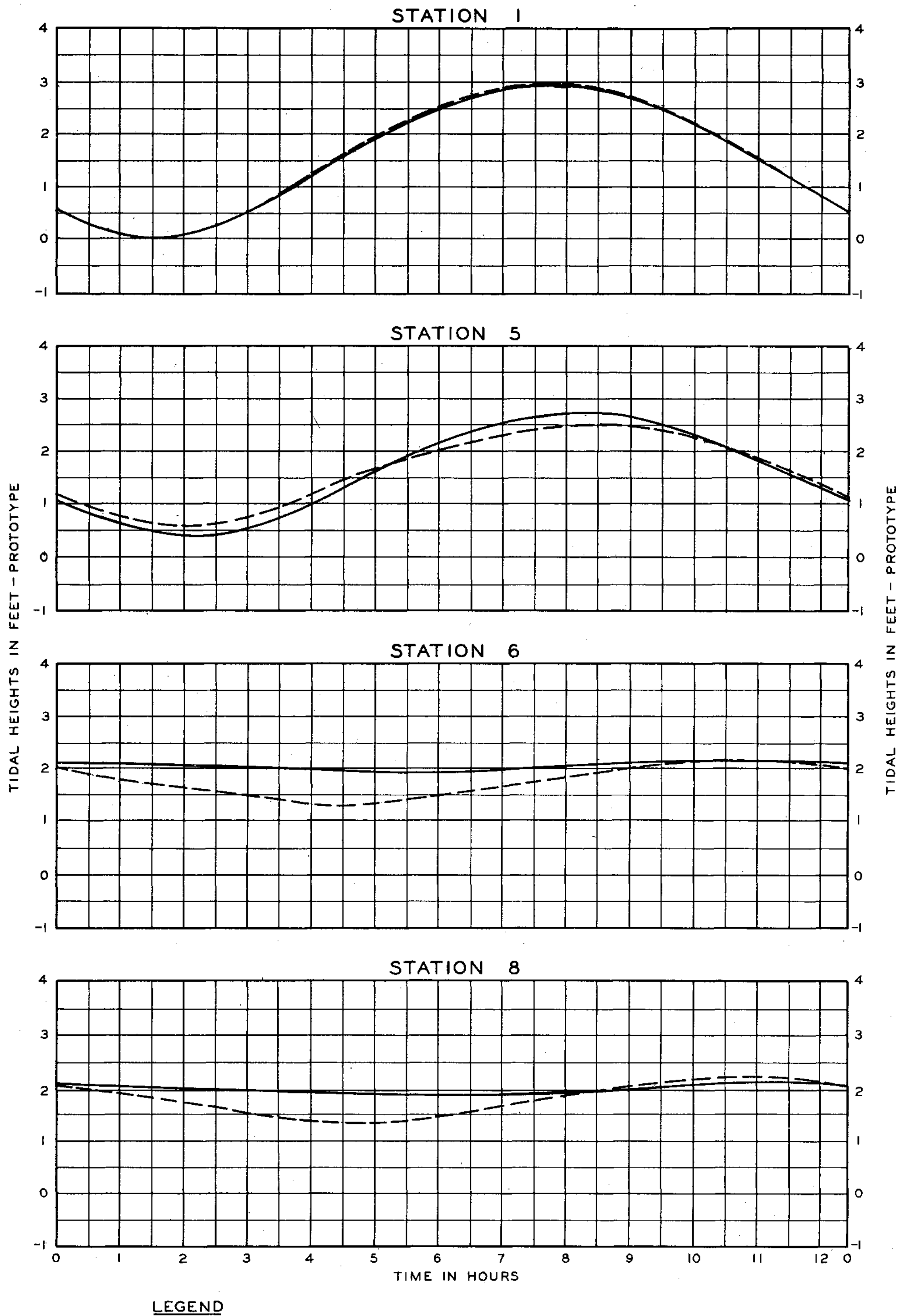
ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 6
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN

VELOCITY CURVES
PLAN 6
SPRING TIDE



LEGEND

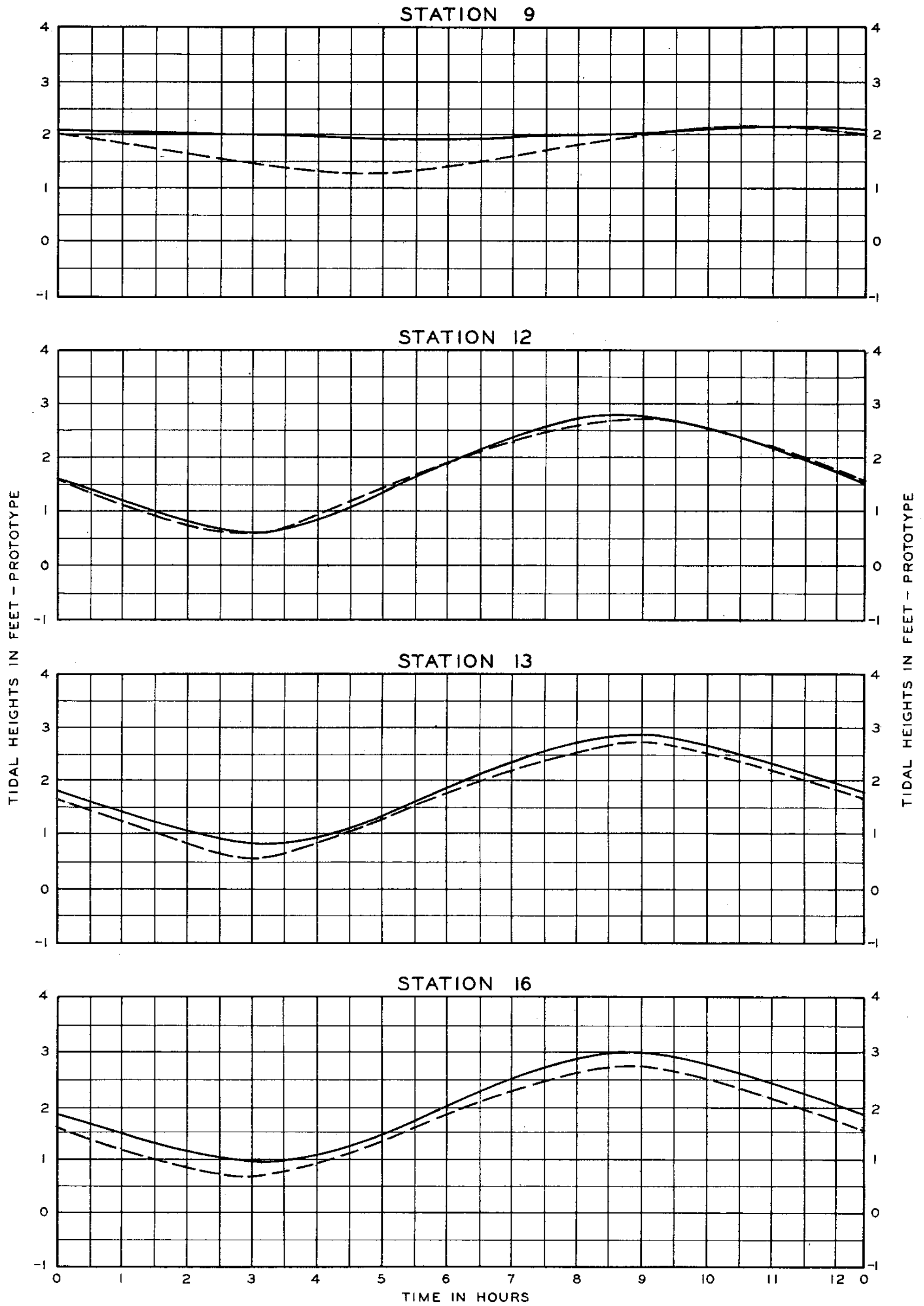
——— BASE TEST TIDAL HEIGHTS.

– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 7
SPRING TIDE



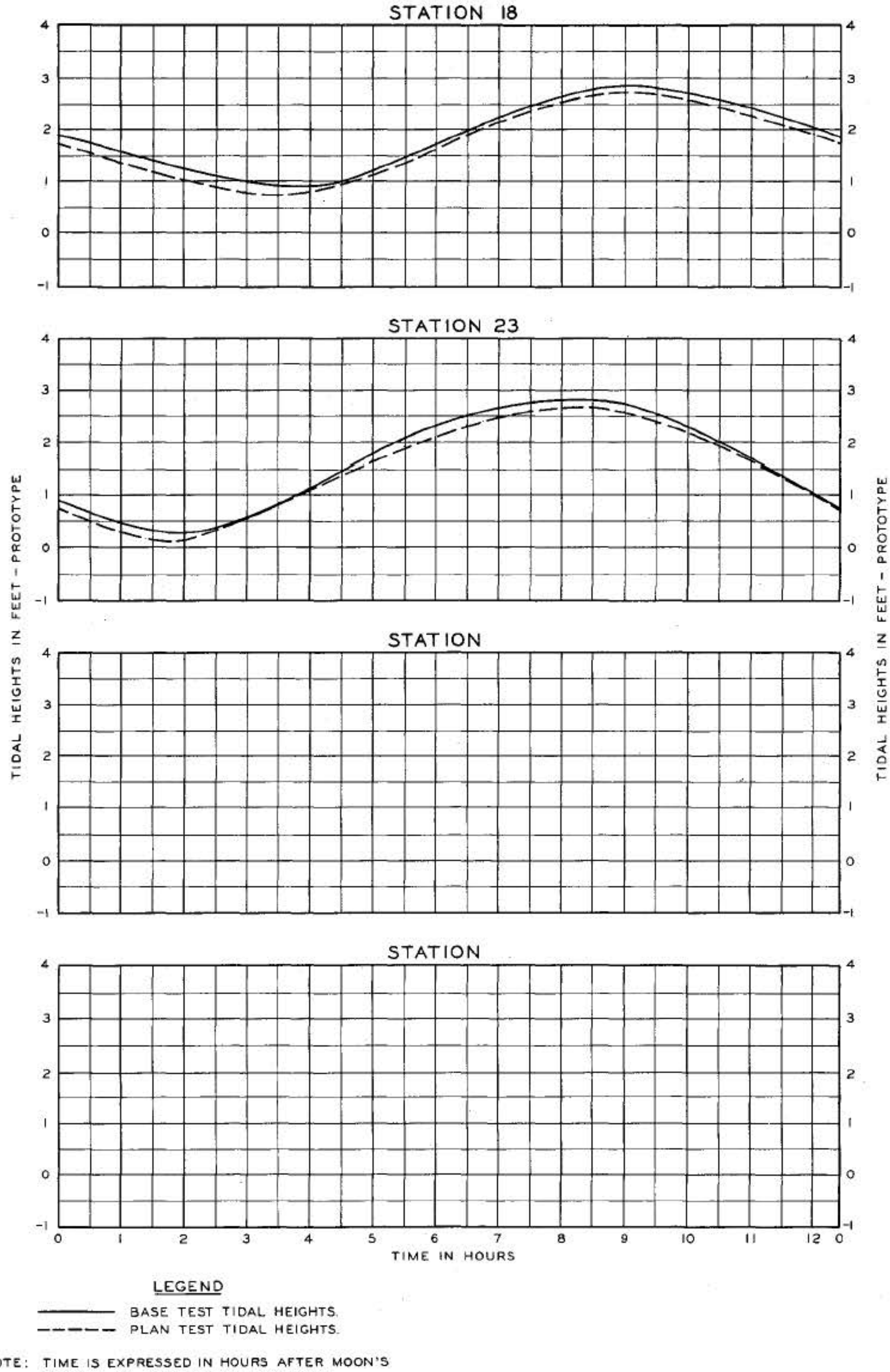
LEGEND

——— BASE TEST TIDAL HEIGHTS.
– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

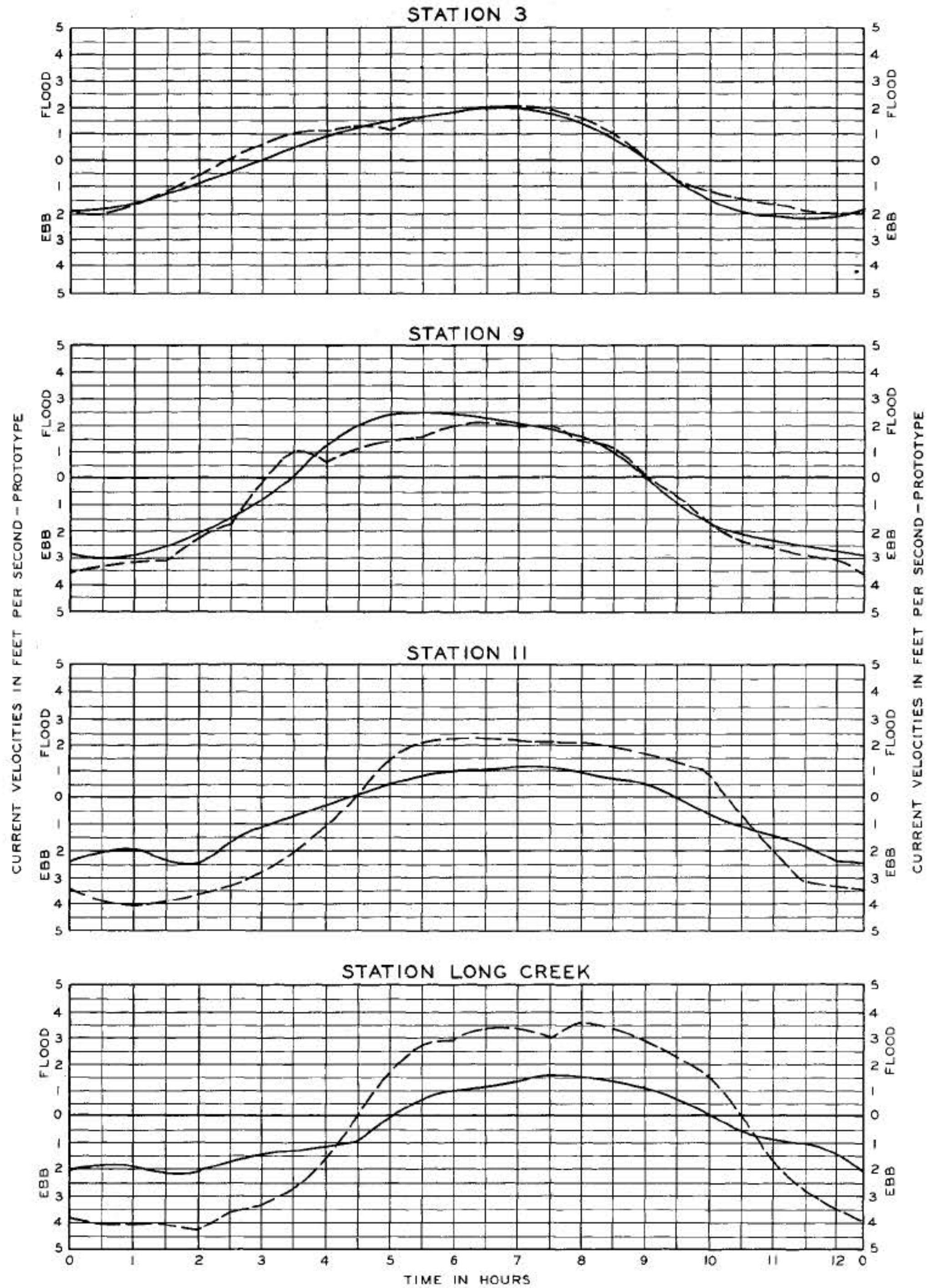
TIDE CURVES
PLAN 7
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 7
SPRING TIDE

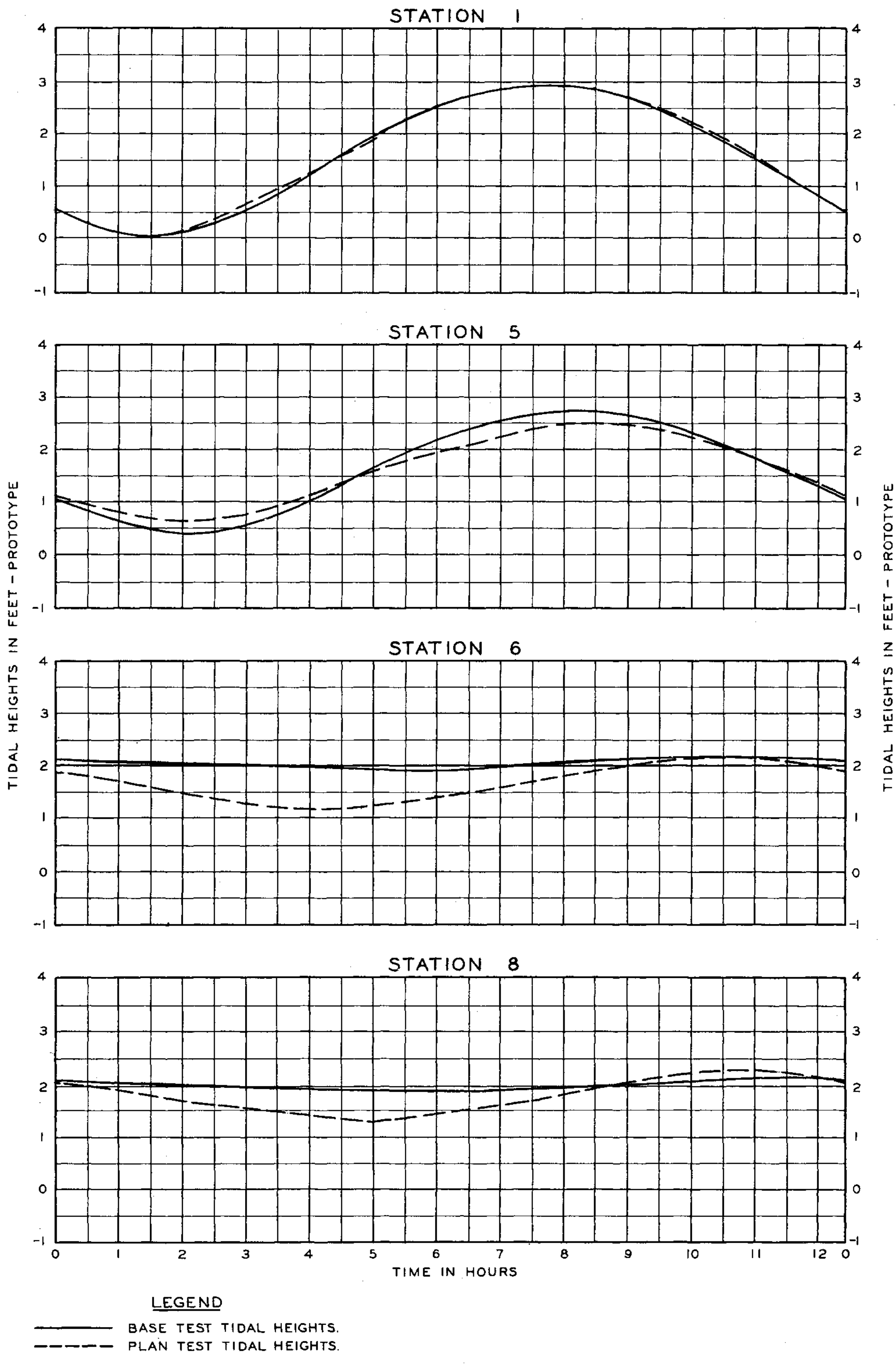


LEGEND

——— BASE TEST VELOCITIES
– – – – PLAN TEST VELOCITIES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

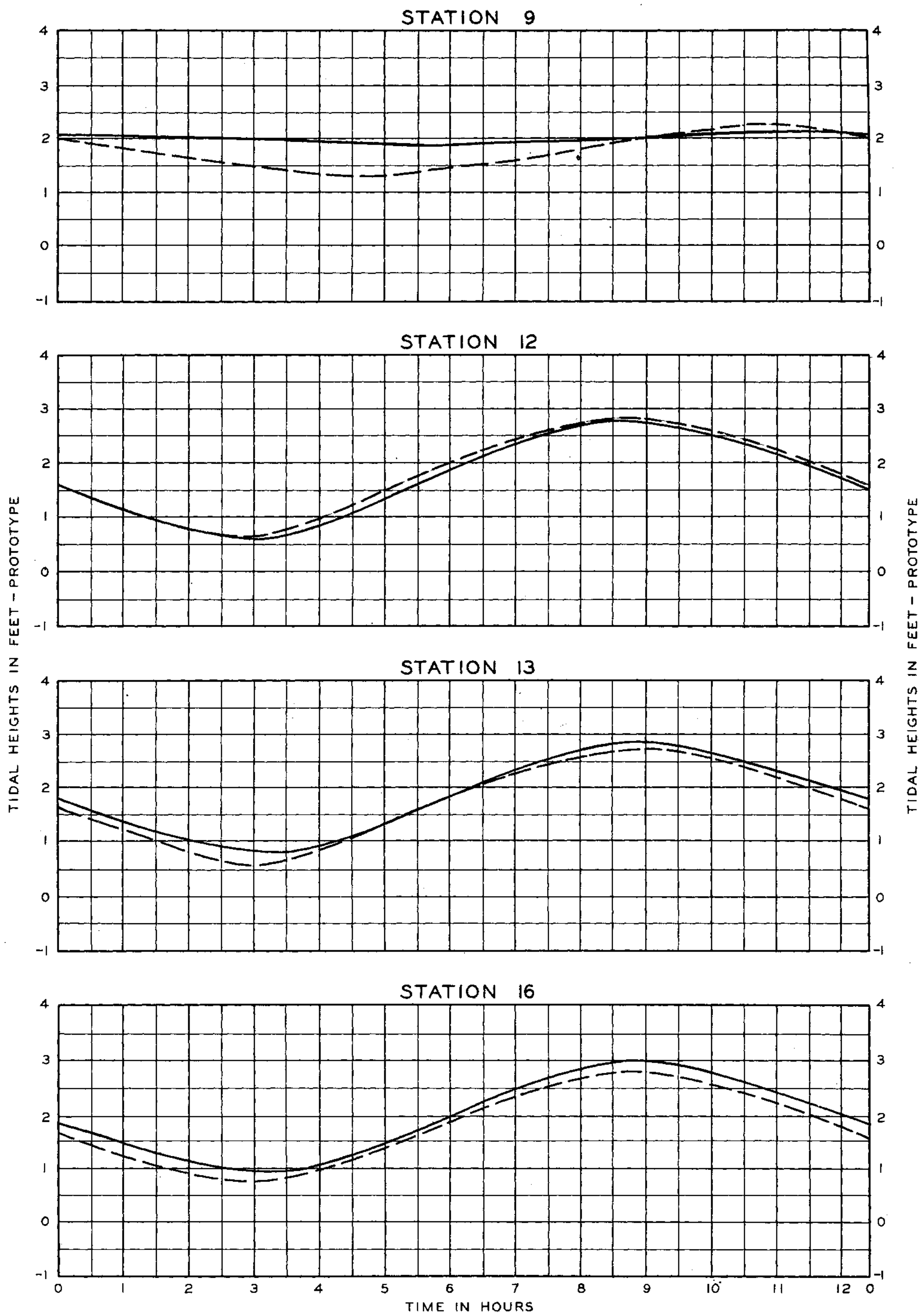
VELOCITY CURVES
PLAN 7
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 8
SPRING TIDE



LEGEND

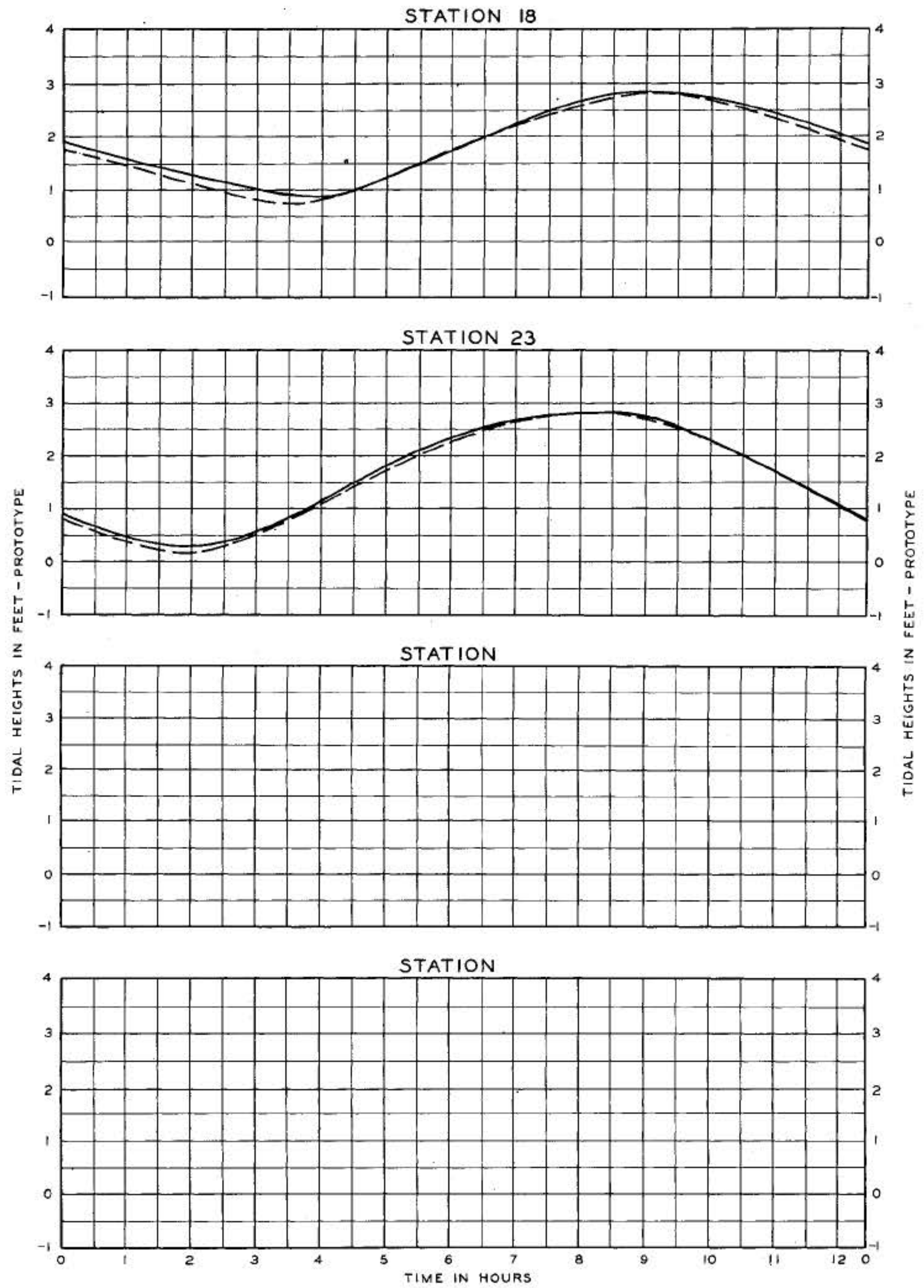
———— BASE TEST TIDAL HEIGHTS.

– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 8
SPRING TIDE



LEGEND

——— BASE TEST TIDAL HEIGHTS.

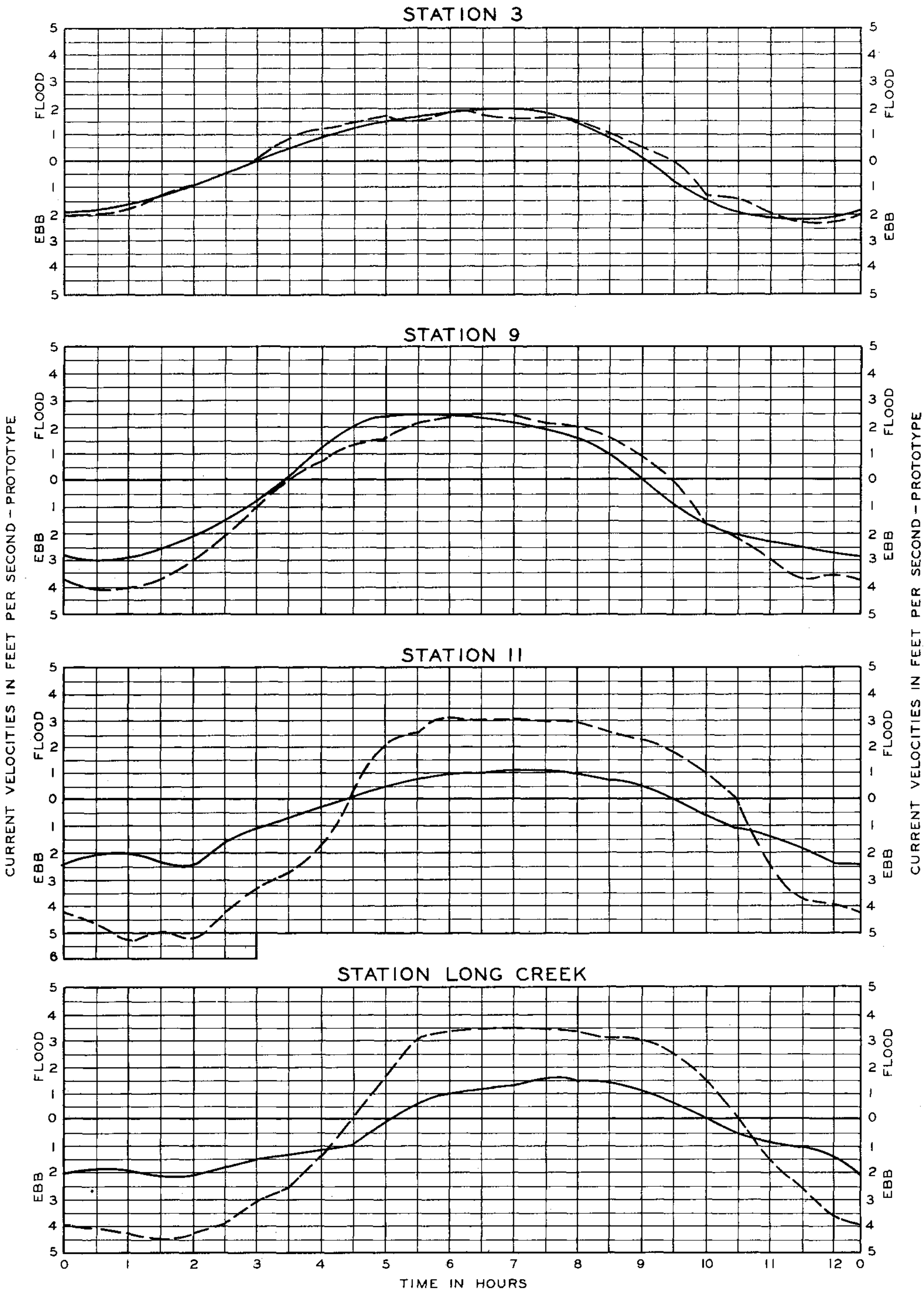
– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 8
SPRING TIDE

PLATE 39



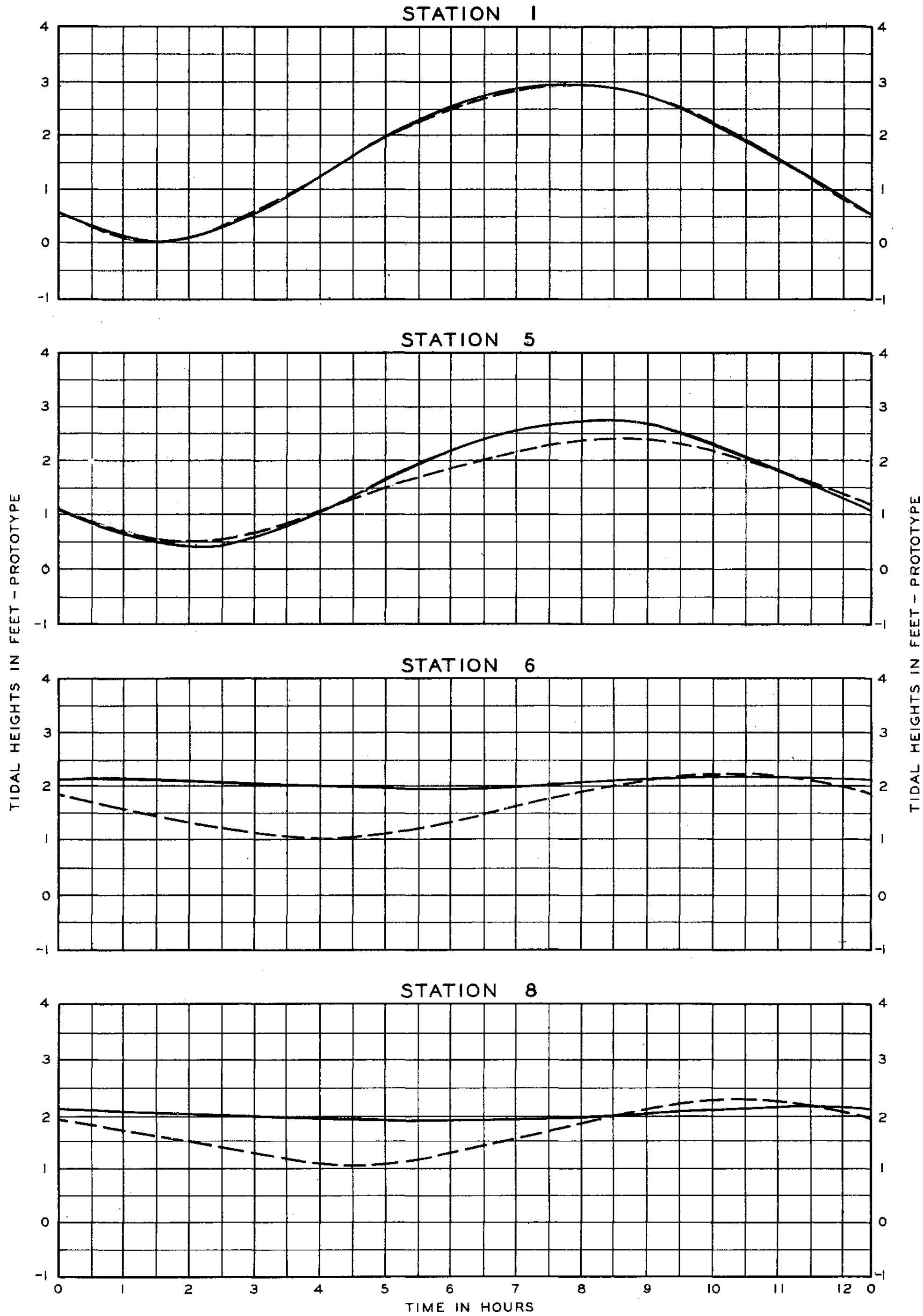
LEGEND

——— BASE TEST VELOCITIES

– – – – PLAN TEST VELOCITIES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

VELOCITY CURVES
PLAN 8
SPRING TIDE



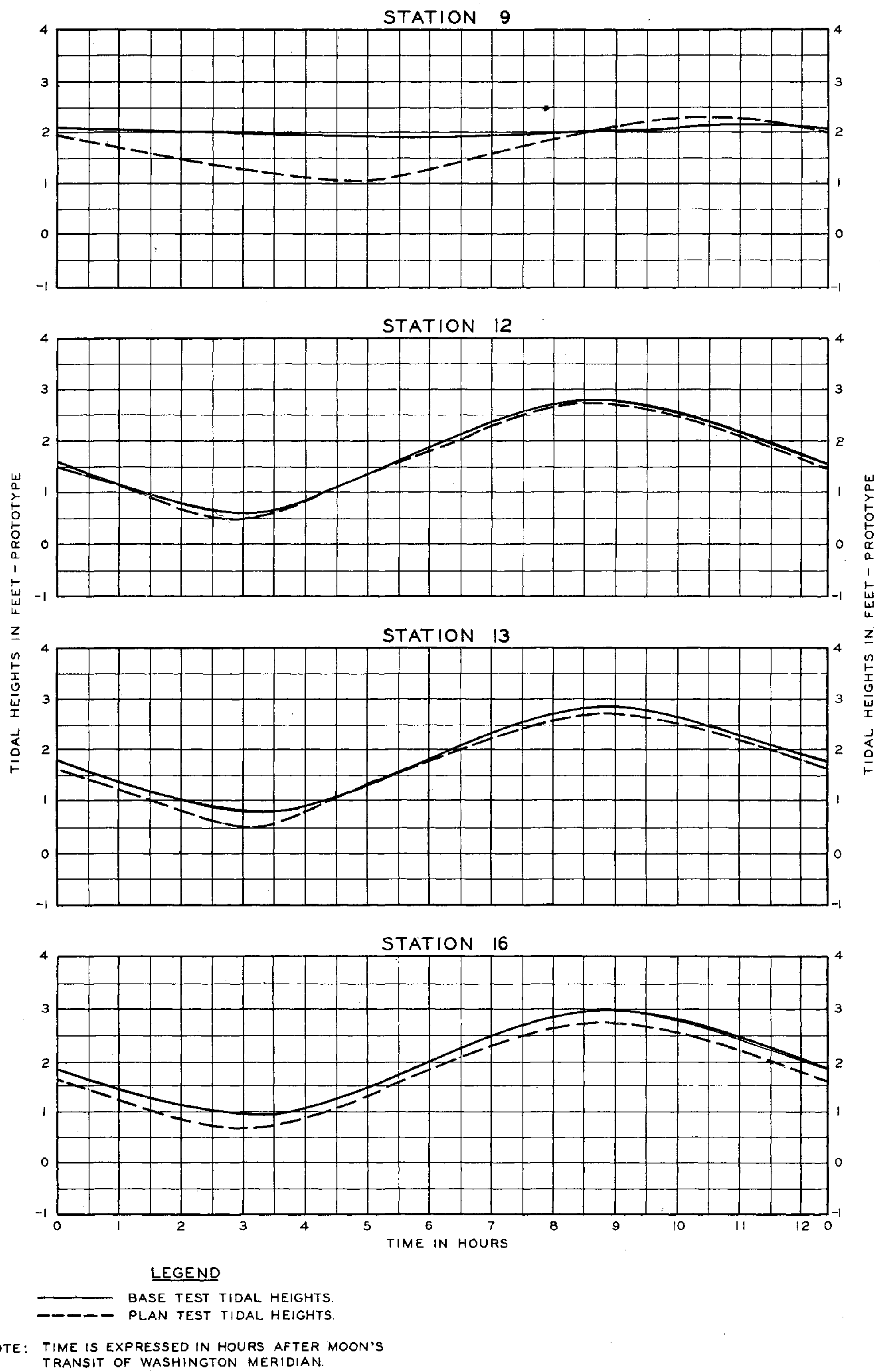
LEGEND

——— BASE TEST TIDAL HEIGHTS.
– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

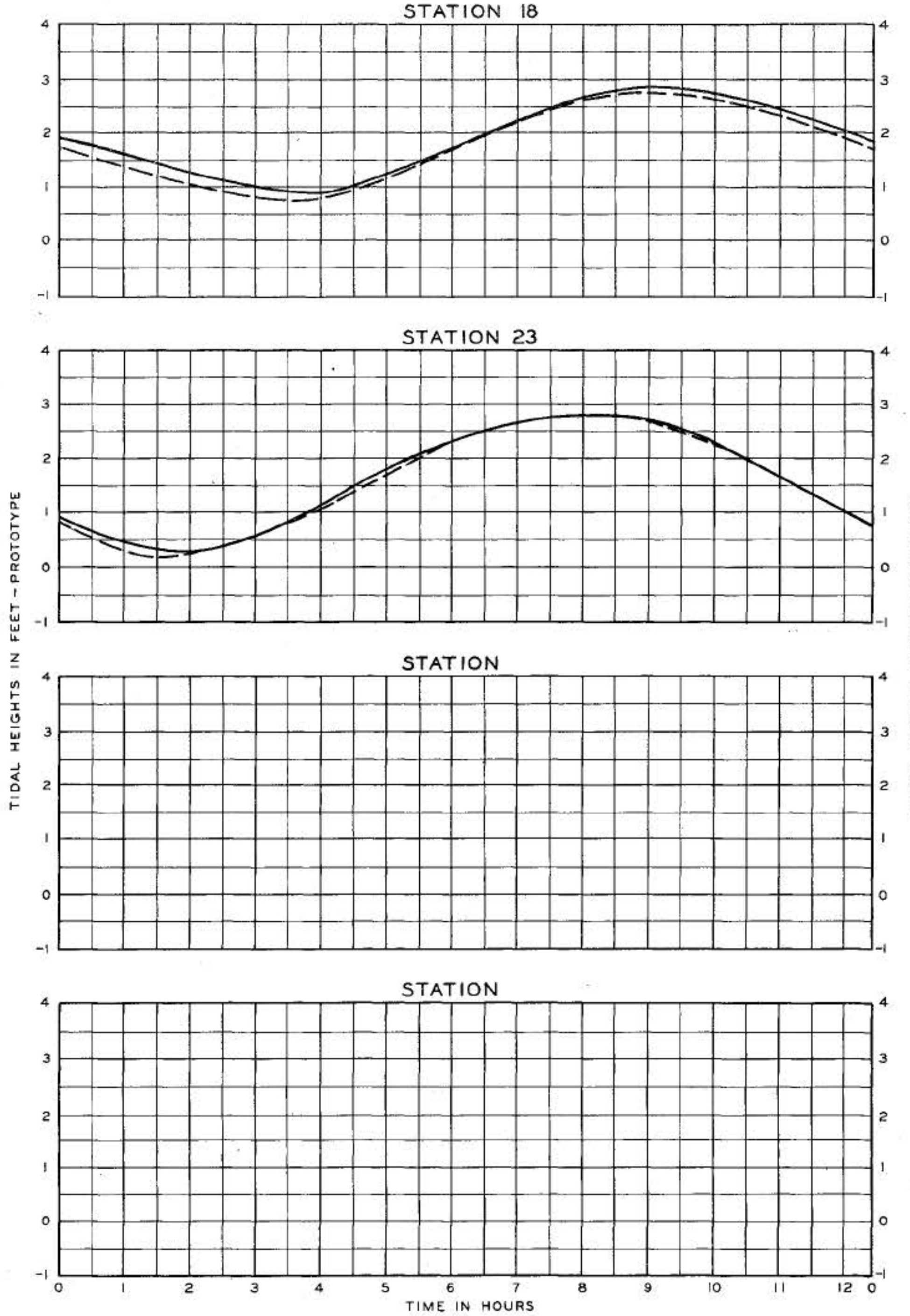
TIDE CURVES
PLAN 9
SPRING TIDE



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 9
SPRING TIDE



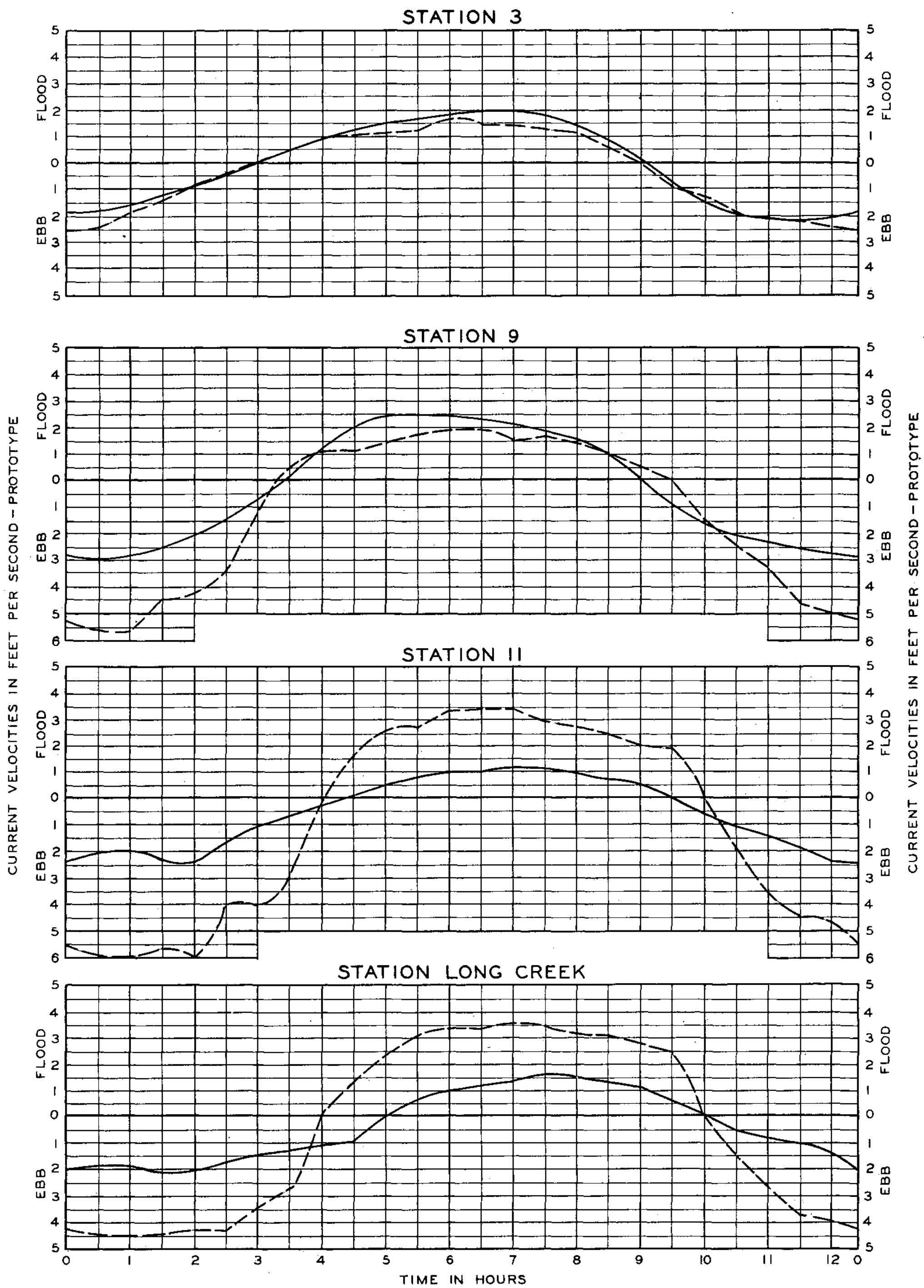
LEGEND

BASE TEST TIDAL HEIGHTS.
PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 9
SPRING TIDE

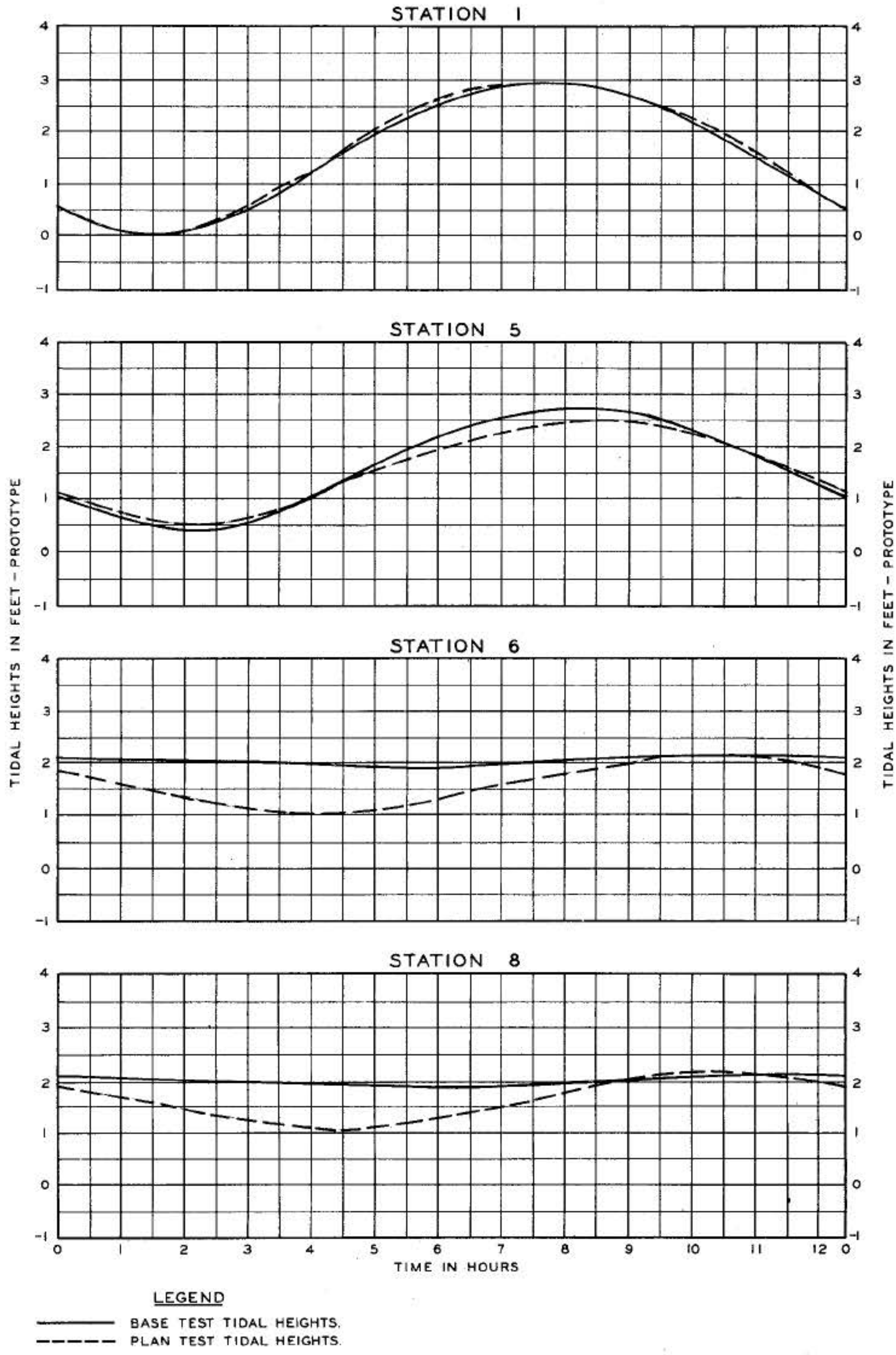


LEGEND

——— BASE TEST VELOCITIES
– – – – PLAN TEST VELOCITIES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

VELOCITY CURVES
PLAN 9
SPRING TIDE

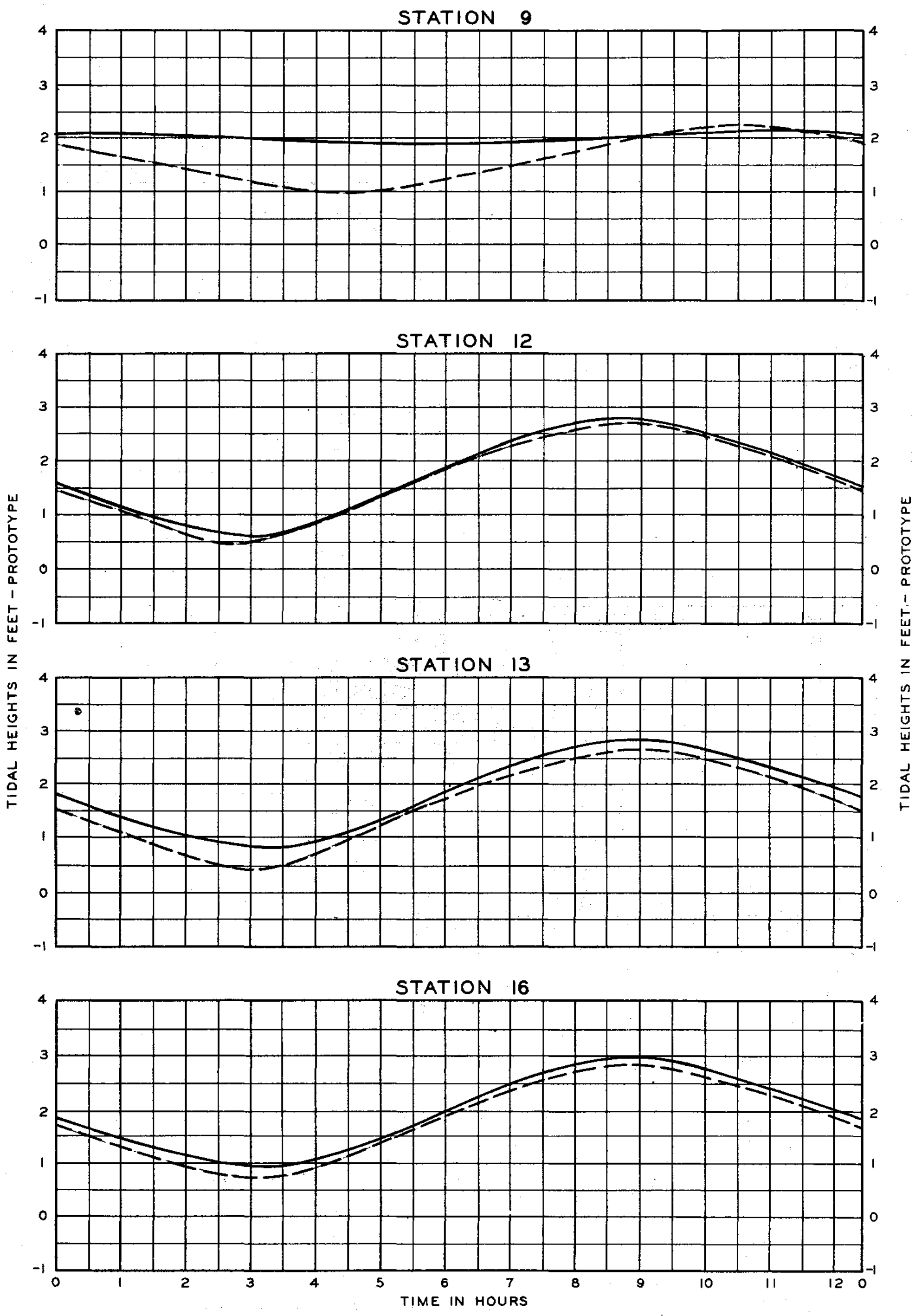


NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 10
SPRING TIDE

PLATE 45



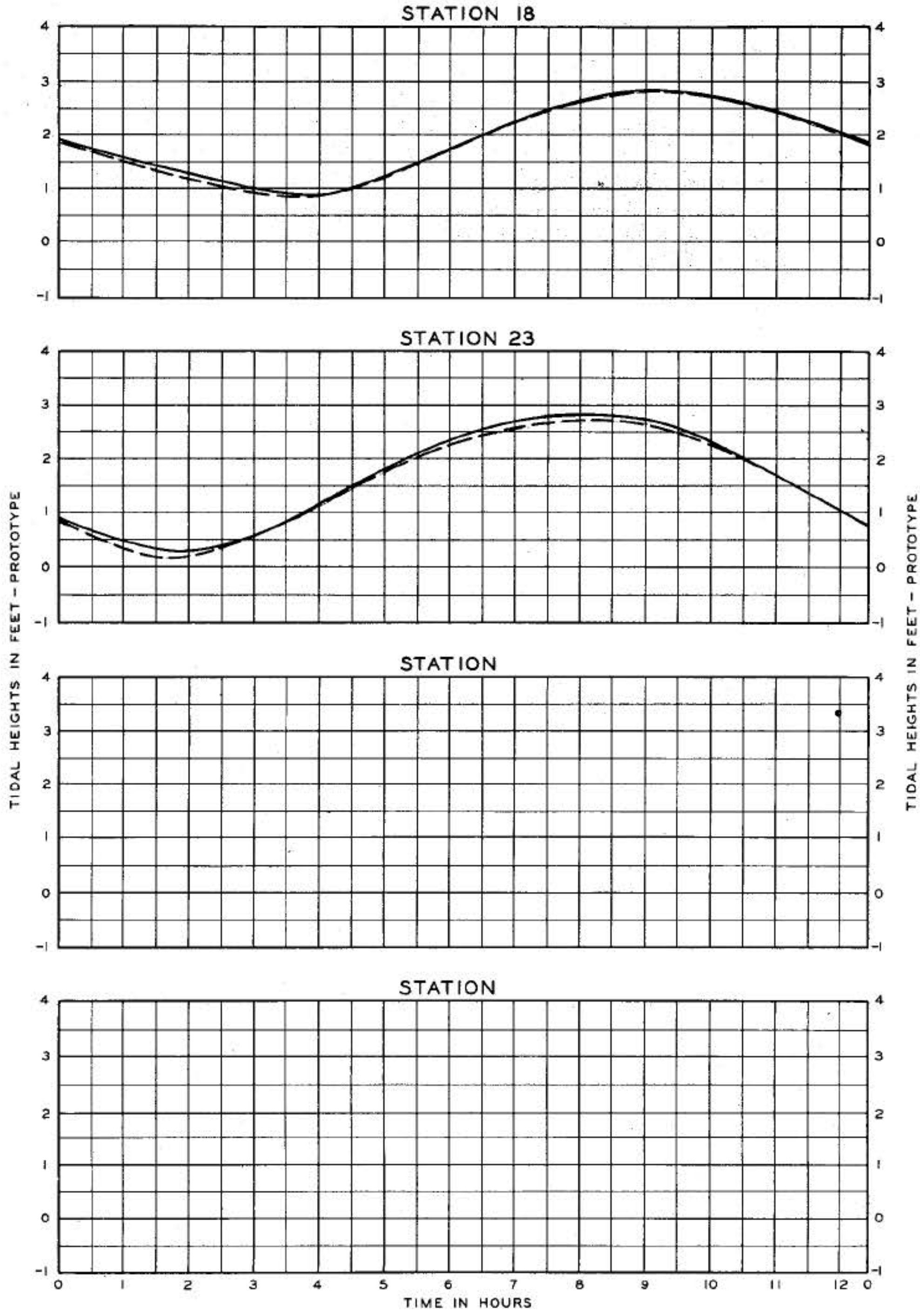
LEGEND

——— BASE TEST TIDAL HEIGHTS.
– – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 10
SPRING TIDE



LEGEND

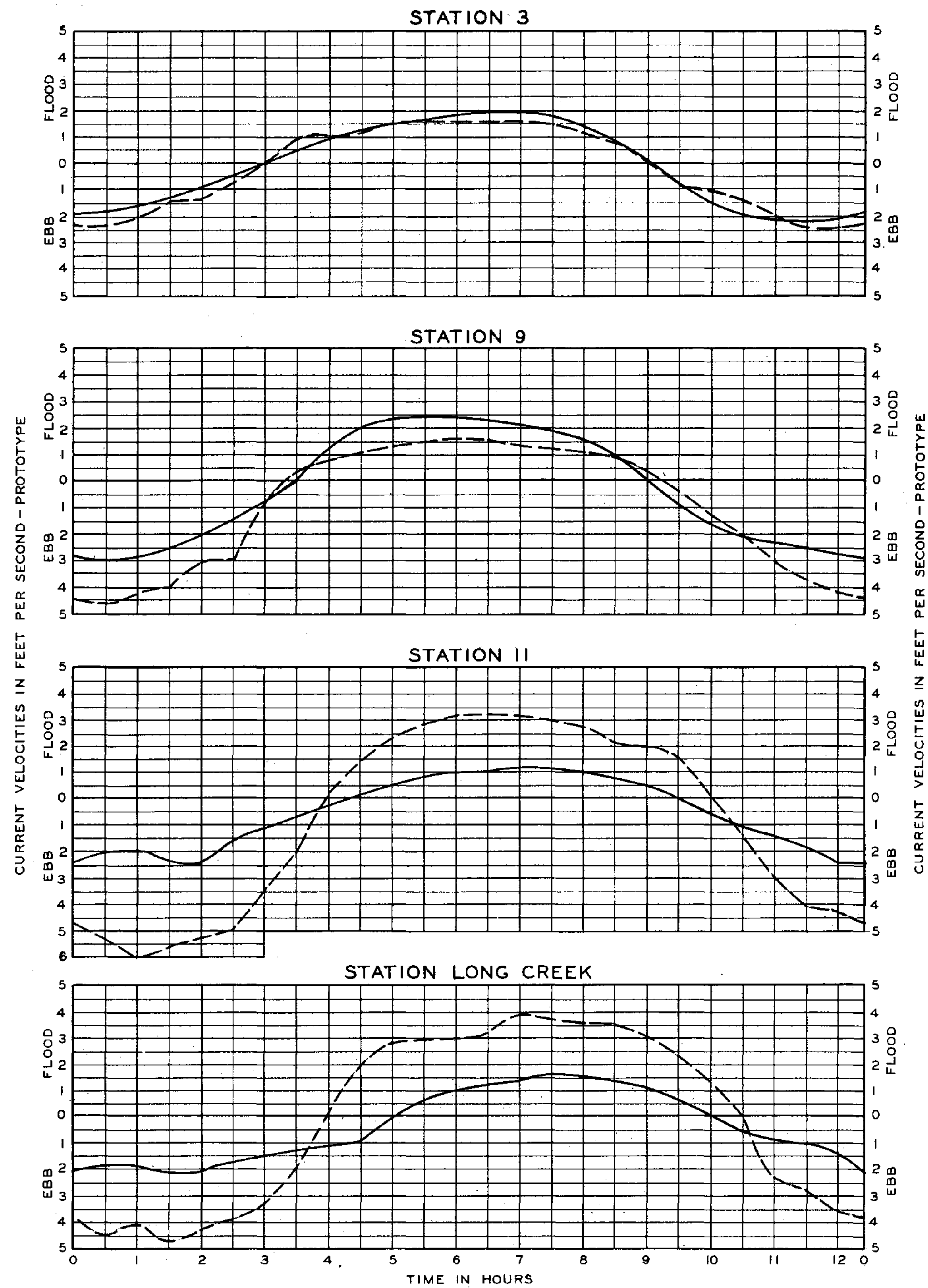
——— BASE TEST TIDAL HEIGHTS.

– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 10
SPRING TIDE



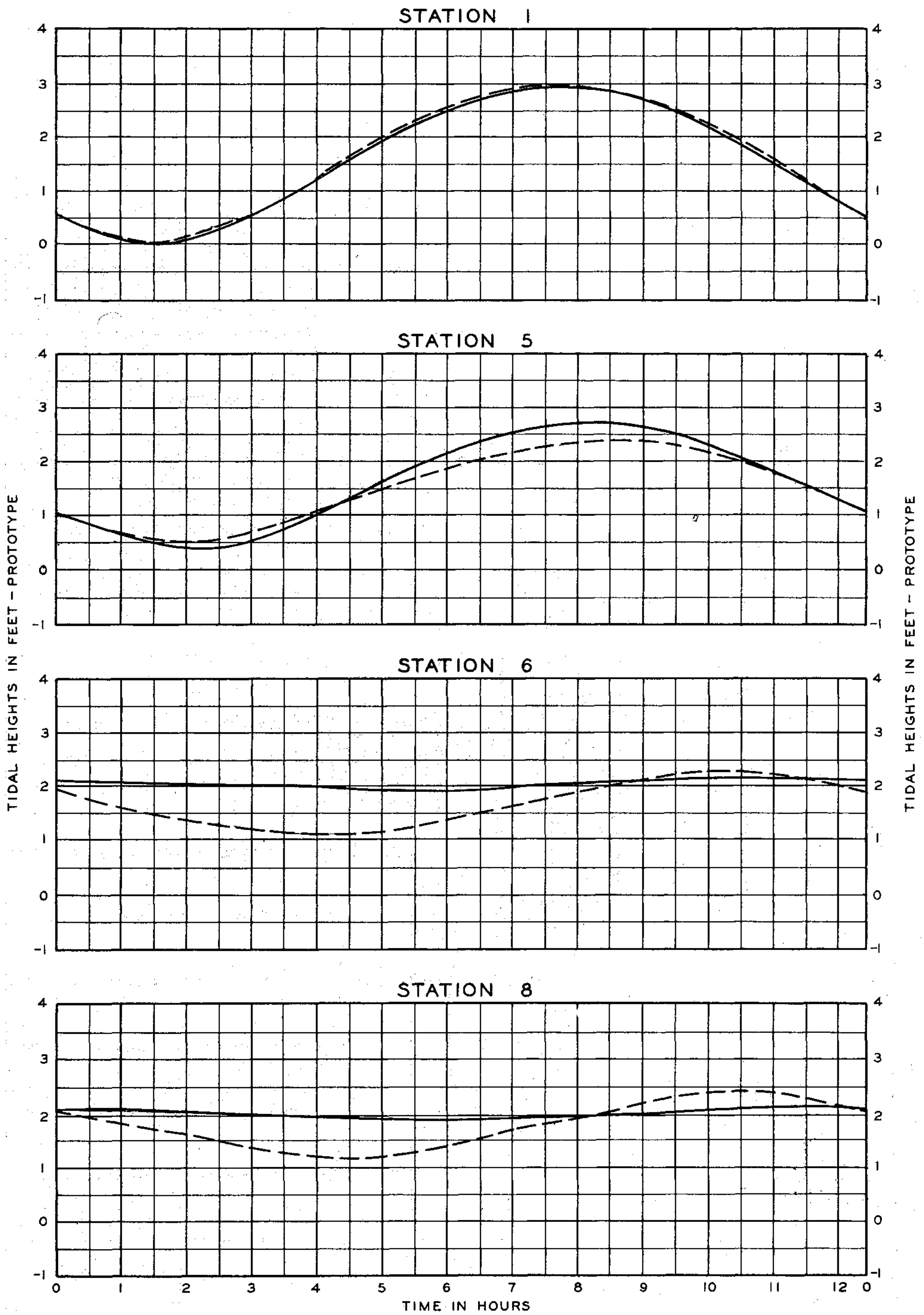
LEGEND

——— BASE TEST VELOCITIES

– – – – PLAN TEST VELOCITIES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

VELOCITY CURVES
PLAN 10
SPRING TIDE



LEGEND

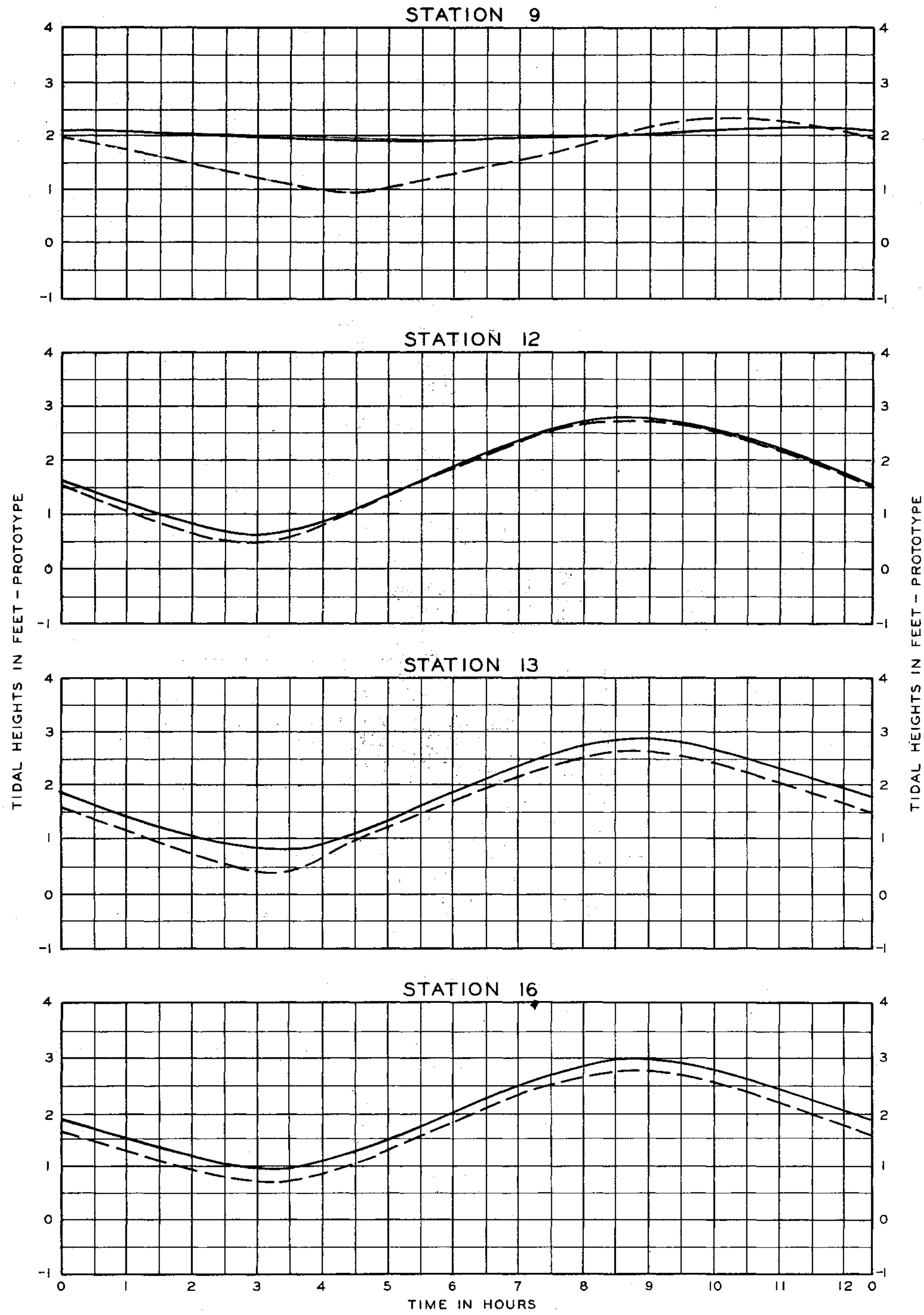
——— BASE TEST TIDAL HEIGHTS.

– – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 11
SPRING TIDE



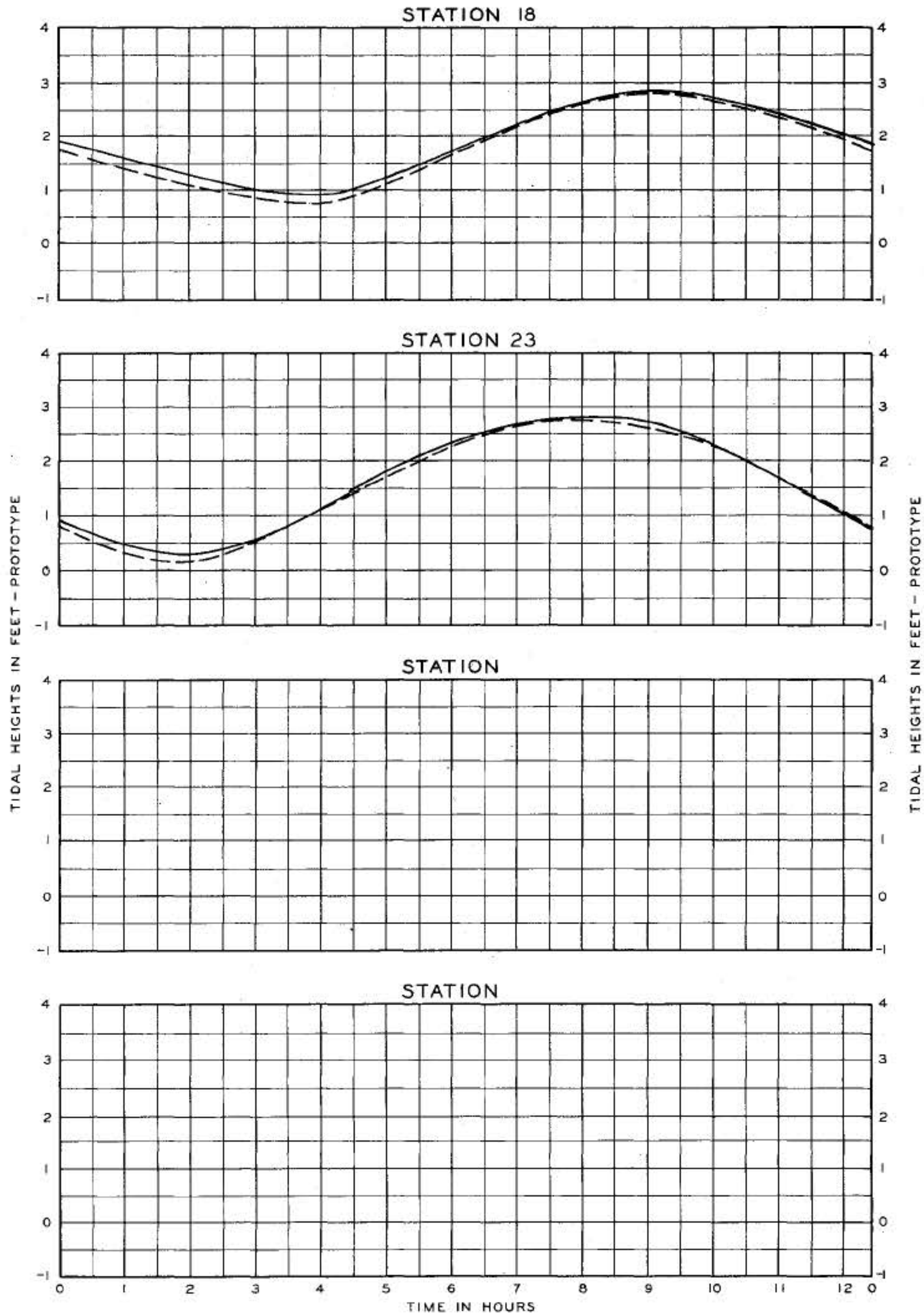
LEGEND

——— BASE TEST TIDAL HEIGHTS.
– – – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 11
SPRING TIDE



LEGEND

—— BASE TEST TIDAL HEIGHTS.

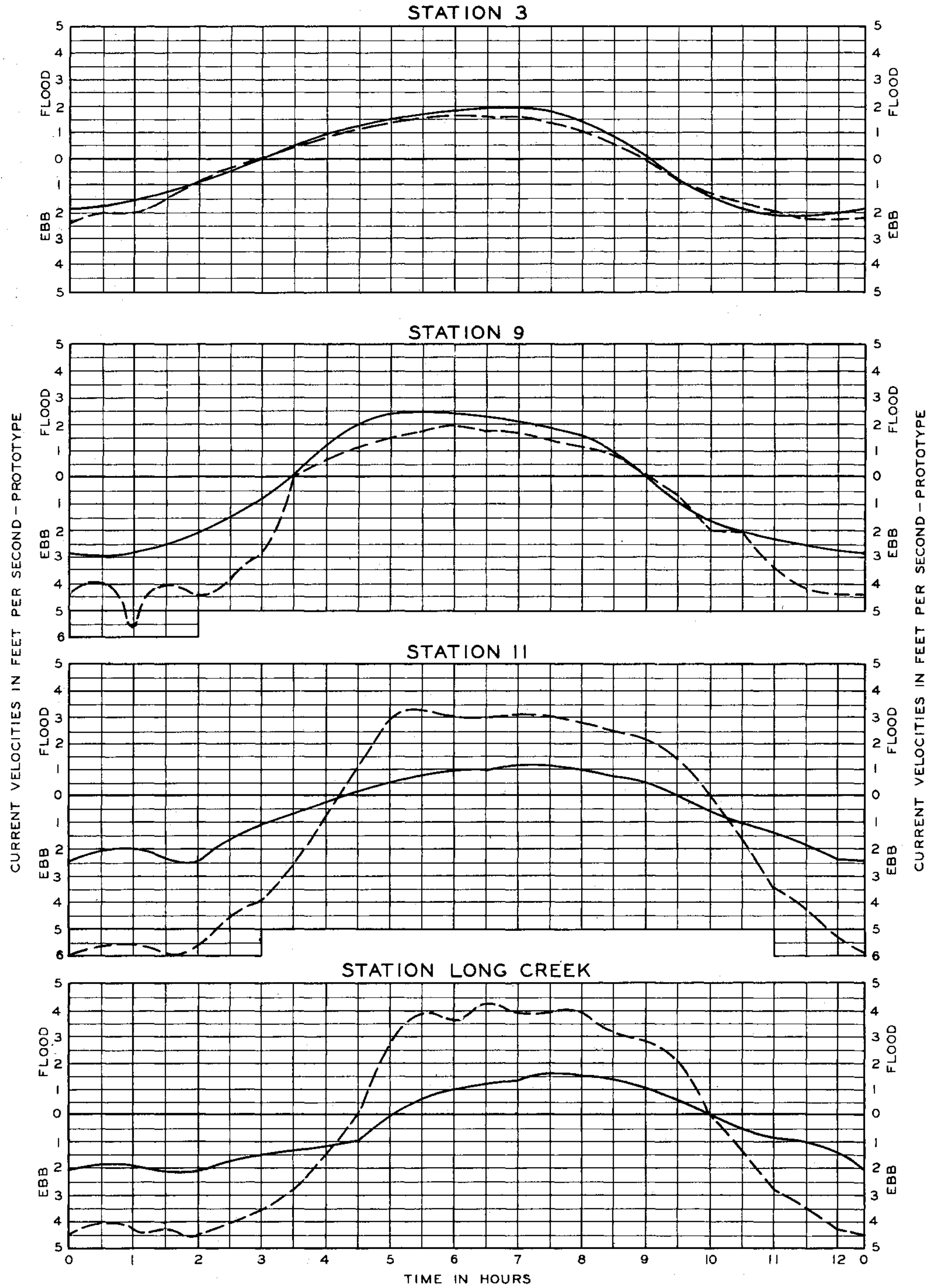
– – – PLAN TEST TIDAL HEIGHTS.

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

ELEVATIONS REFER TO LW NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.

TIDE CURVES
PLAN 11
SPRING TIDE

PLATE 51



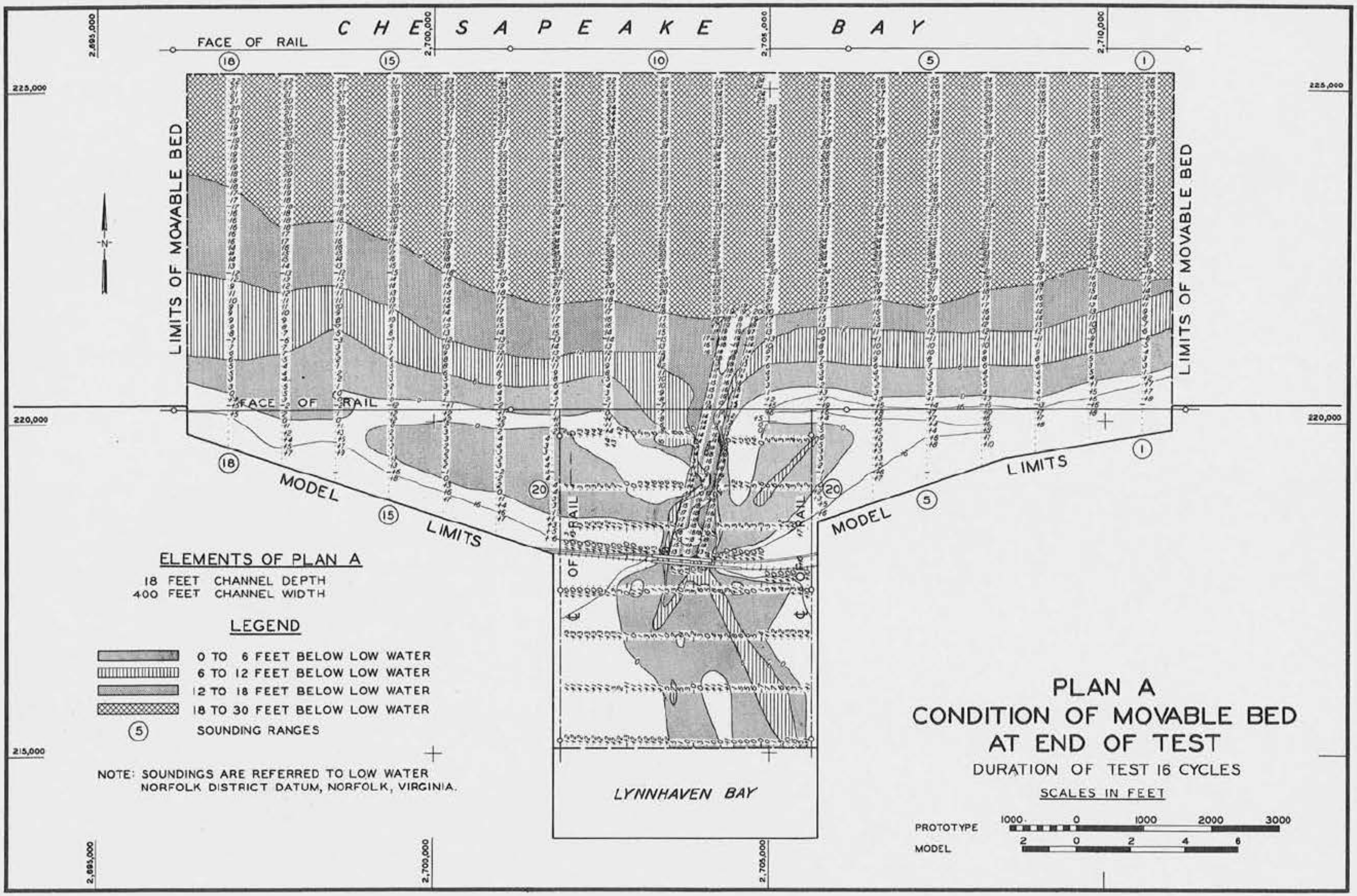
LEGEND

——— BASE TEST VELOCITIES

– – – – PLAN TEST VELOCITIES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF WASHINGTON MERIDIAN.

VELOCITY CURVES
PLAN 11
SPRING TIDE



PLAN A
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES

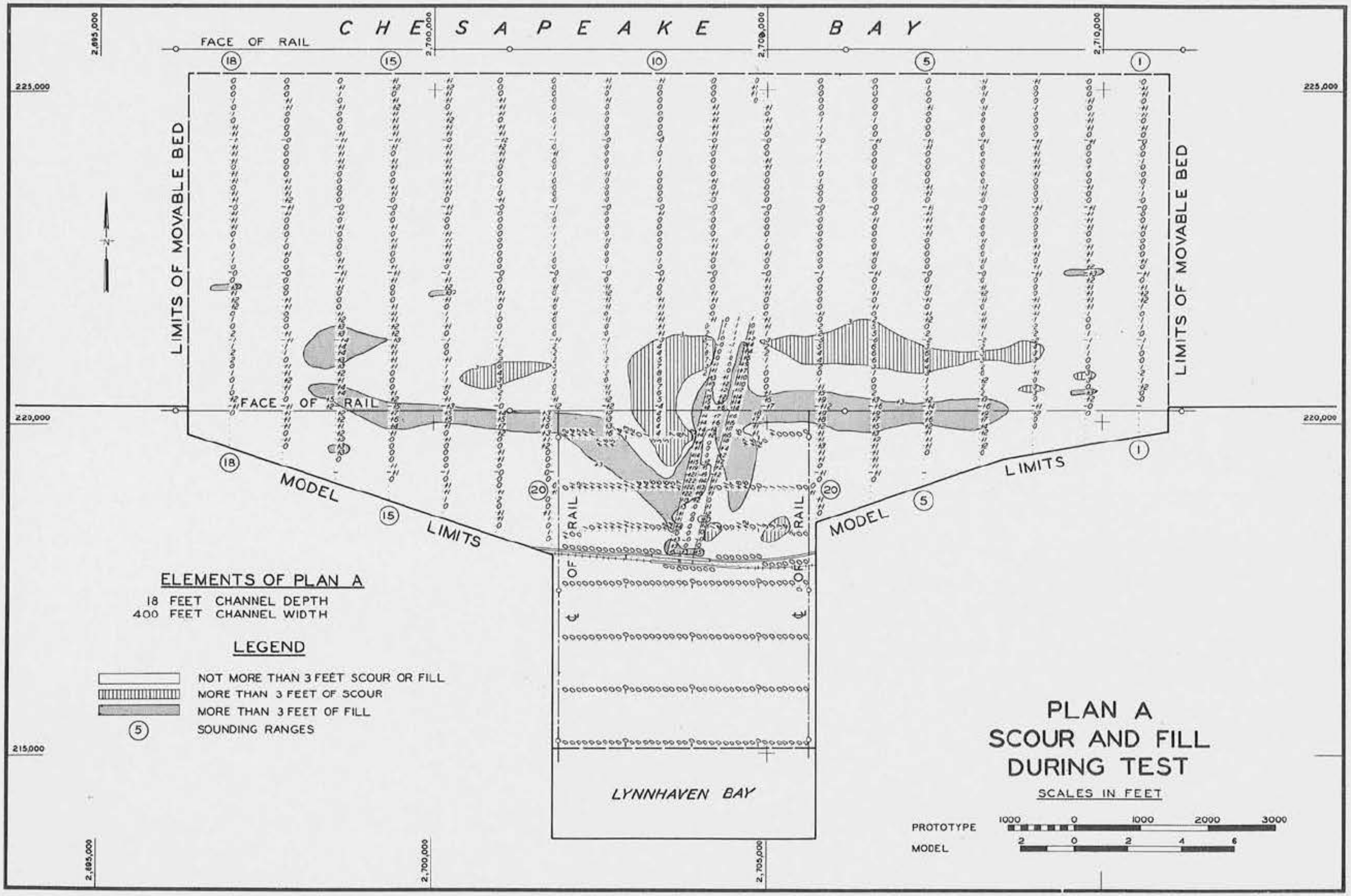
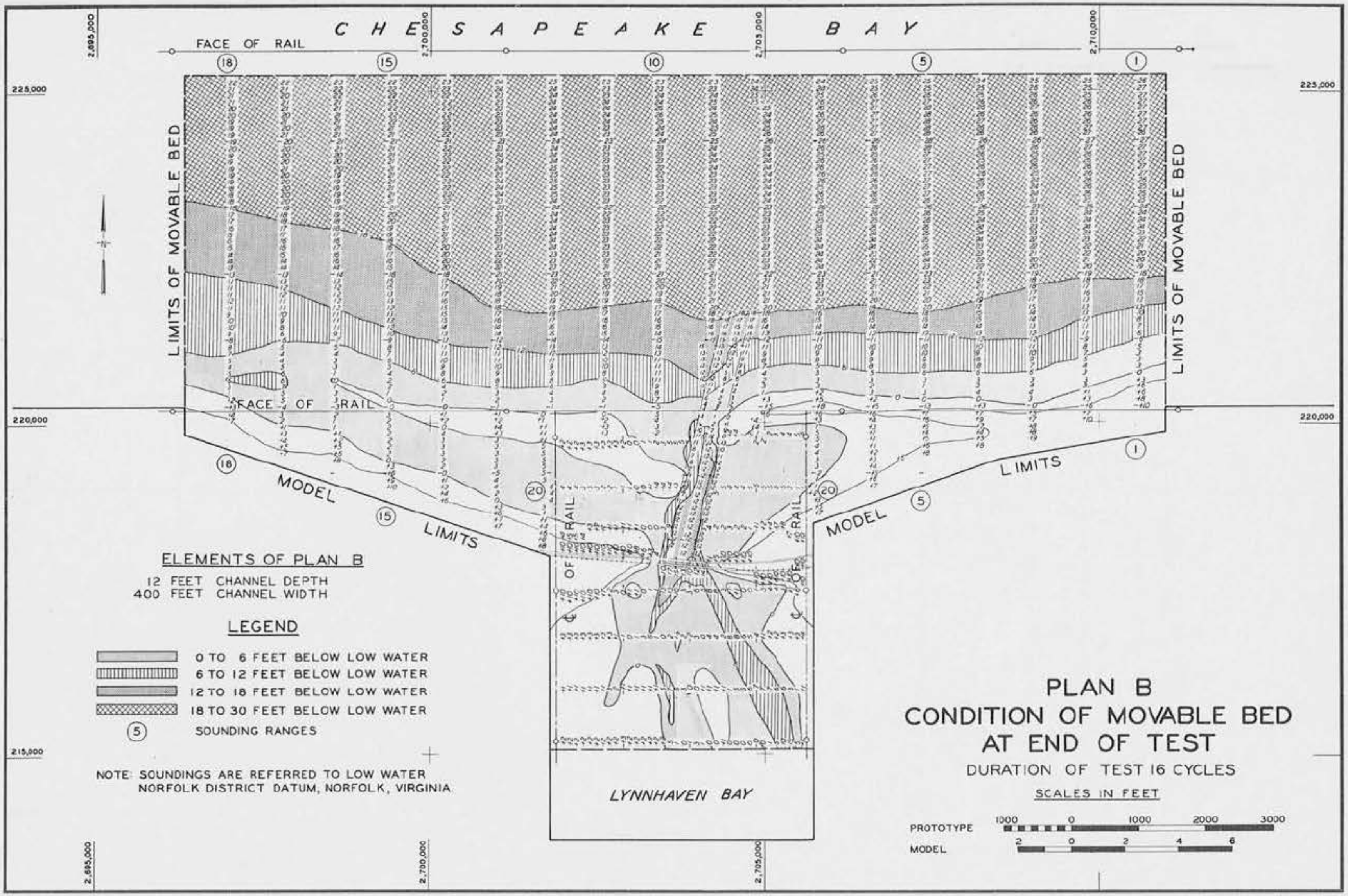
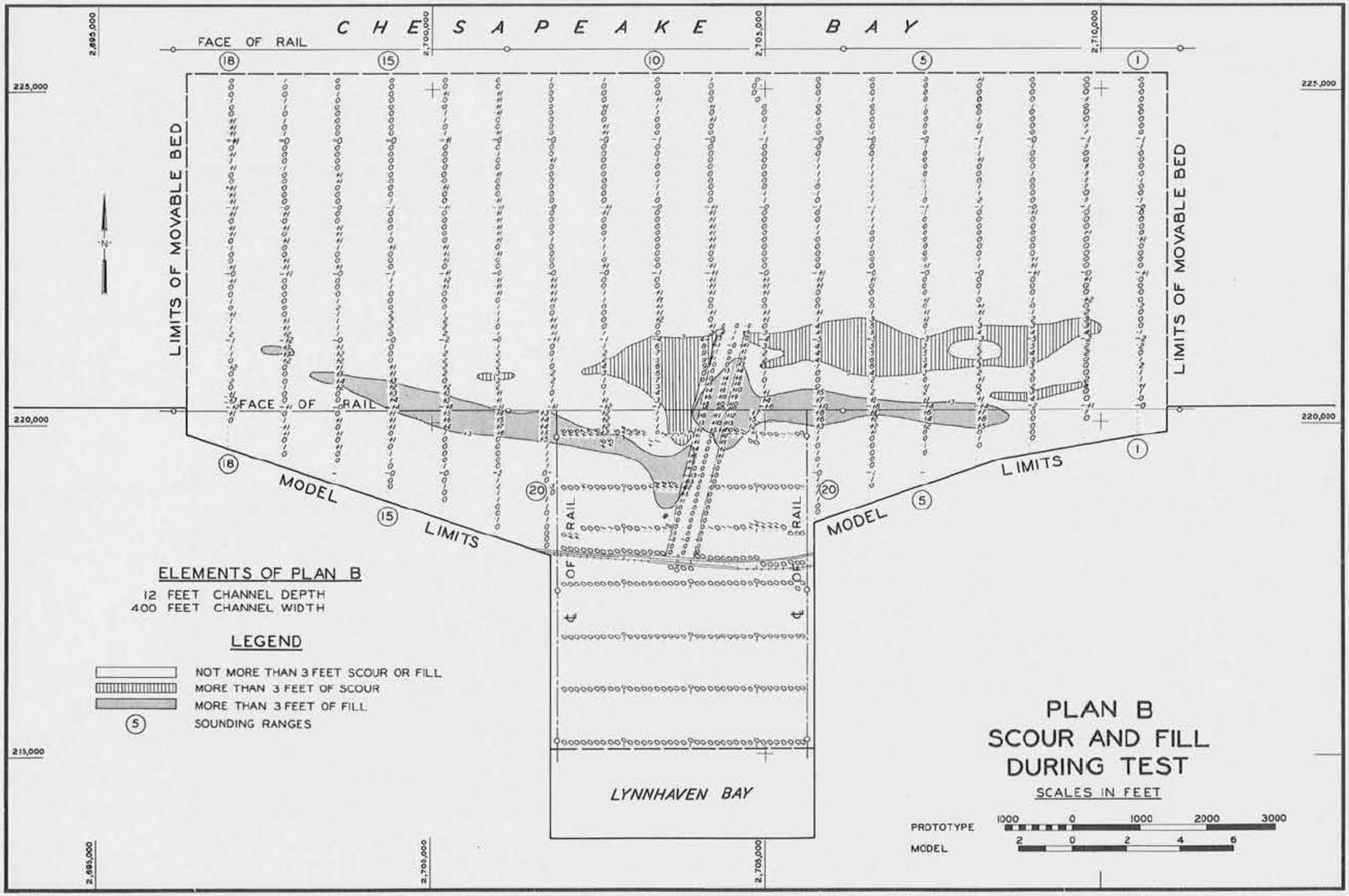

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
LIMITS OF MOVABLE BED
N
MODEL LIMITS
MODEL LIMITS
OF RAIL
OF RAIL
LYNNHAVEN BAY
ELEMENTS OF PLAN A
18 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
SOUNDING RANGES
PLAN A
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE
MODEL
1000 0 1000 2000 3000
2 0 2 4 6
225,000
220,000
215,000
2,695,000
2,700,000
2,705,000
2,710,000

PLATE 54

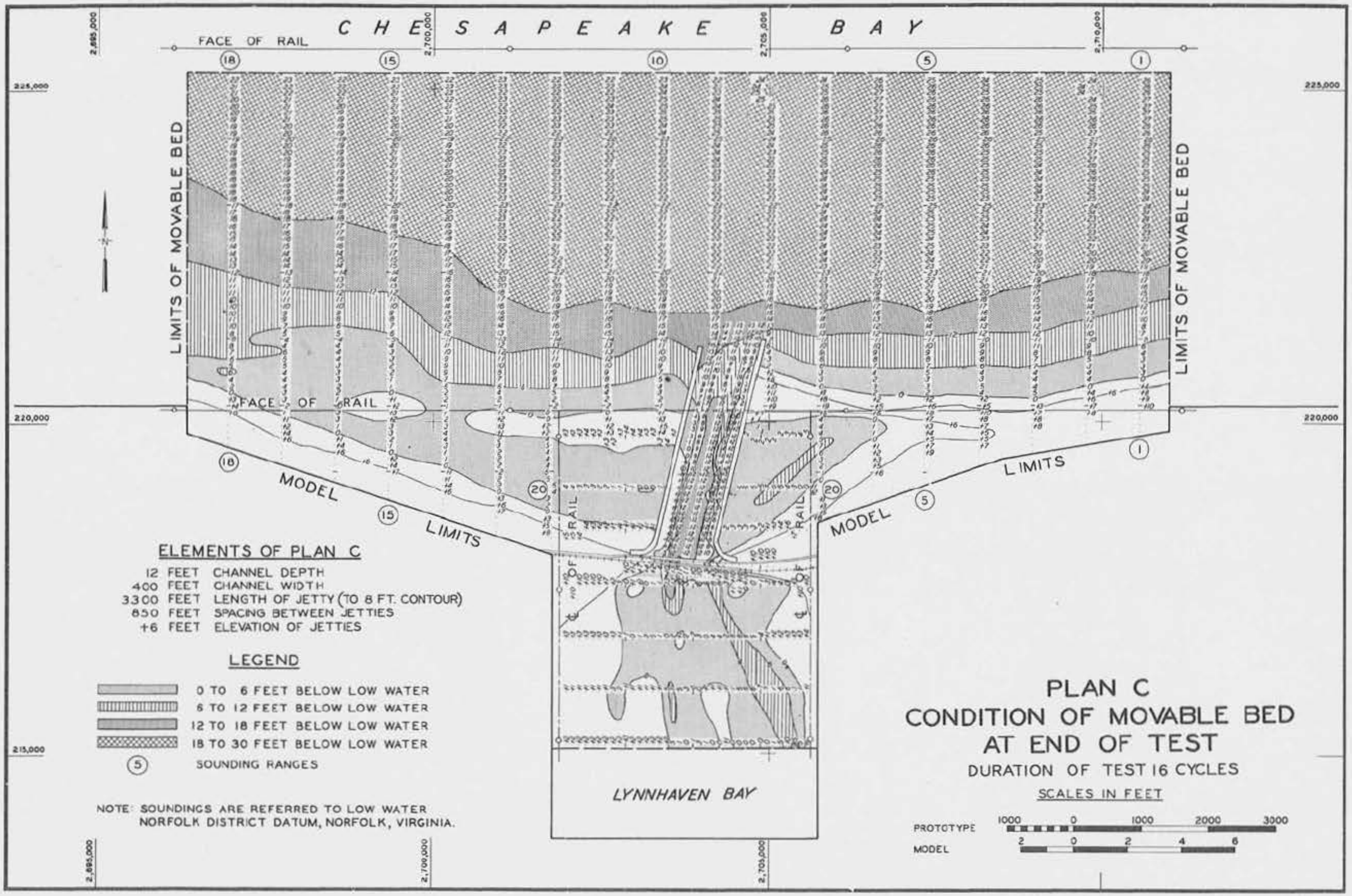

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
OF RAIL
LYNNHAVEN BAY
225,000
220,000
215,000
2,695,000
2,700,000
2,705,000
2,710,000
ELEMENTS OF PLAN B
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
LEGEND
0 TO 6 FEET BELOW LOW WATER
6 TO 12 FEET BELOW LOW WATER
12 TO 18 FEET BELOW LOW WATER
18 TO 30 FEET BELOW LOW WATER
SOUNDING RANGES
NOTE: SOUNDINGS ARE REFERRED TO LOW WATER
NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA
PLAN B
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES
SCALES IN FEET
PROTOTYPE
1000 0 1000 2000 3000
MODEL
2 0 2 4 6



PLAN B
SCOUR AND FILL
DURING TEST

PLATE 56

PLATE 57



CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
FACE OF RAIL
LYNNHAVEN BAY
ELEMENTS OF PLAN C
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3300 FEET LENGTH OF JETTY (TO 8 FT. CONTOUR)
850 FEET SPACING BETWEEN JETTIES
+6 FEET ELEVATION OF JETTIES
LEGEND
0 TO 6 FEET BELOW LOW WATER
6 TO 12 FEET BELOW LOW WATER
12 TO 18 FEET BELOW LOW WATER
18 TO 30 FEET BELOW LOW WATER
SOUNDING RANGES
NOTE: SOUNDINGS ARE REFERRED TO LOW WATER NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.
PLAN C
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES
SCALES IN FEET
PROTOTYPE
MODEL

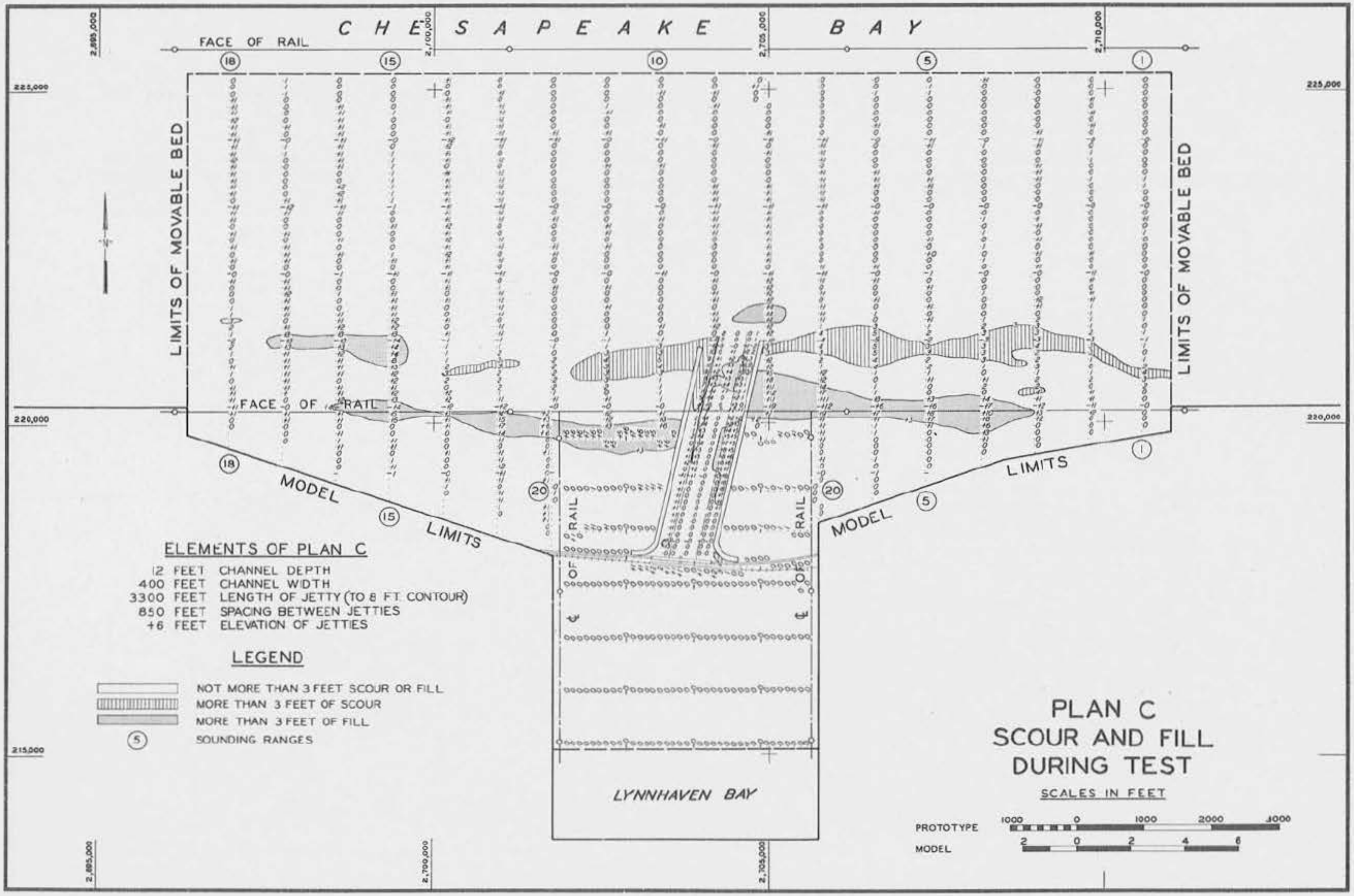
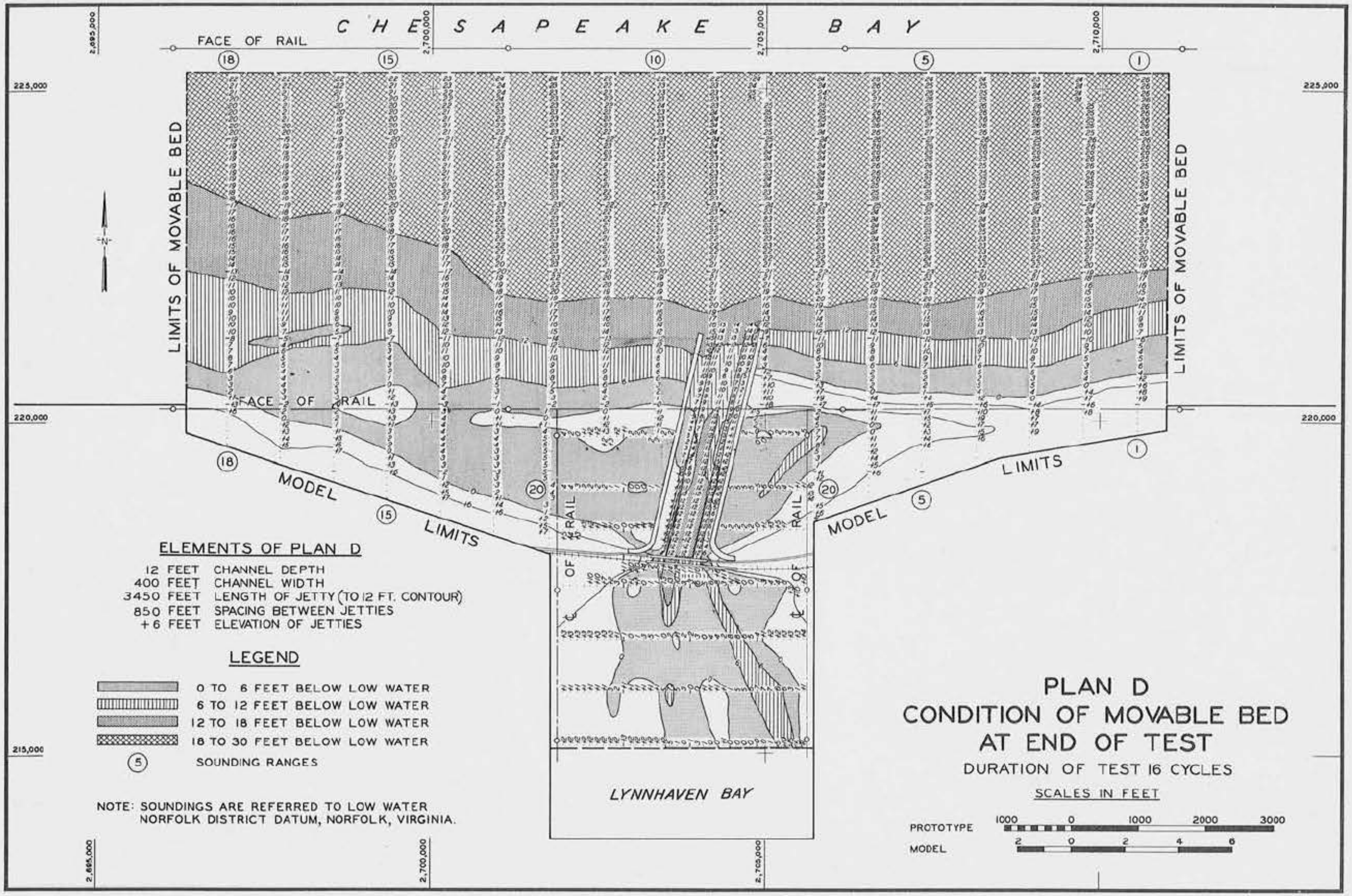

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN C
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3300 FEET LENGTH OF JETTY (TO 8 FT. CONTOUR)
850 FEET SPACING BETWEEN JETTIES
+6 FEET ELEVATION OF JETTIES
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
SOUNDING RANGES
PLAN C
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE
MODEL
2,695,000
2,700,000
2,705,000
2,710,000
225,000
220,000
215,000

PLATE 58

PLATE 59



CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN D
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3450 FEET LENGTH OF JETTY (TO 12 FT. CONTOUR)
850 FEET SPACING BETWEEN JETTIES
+6 FEET ELEVATION OF JETTIES
LEGEND
0 TO 6 FEET BELOW LOW WATER
6 TO 12 FEET BELOW LOW WATER
12 TO 18 FEET BELOW LOW WATER
18 TO 30 FEET BELOW LOW WATER
5 SOUNDING RANGES
NOTE: SOUNDINGS ARE REFERRED TO LOW WATER NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.
PLAN D
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000 3000
MODEL 2 0 2 4 6
2,695,000
2,700,000
2,705,000
2,710,000
225,000
220,000
215,000

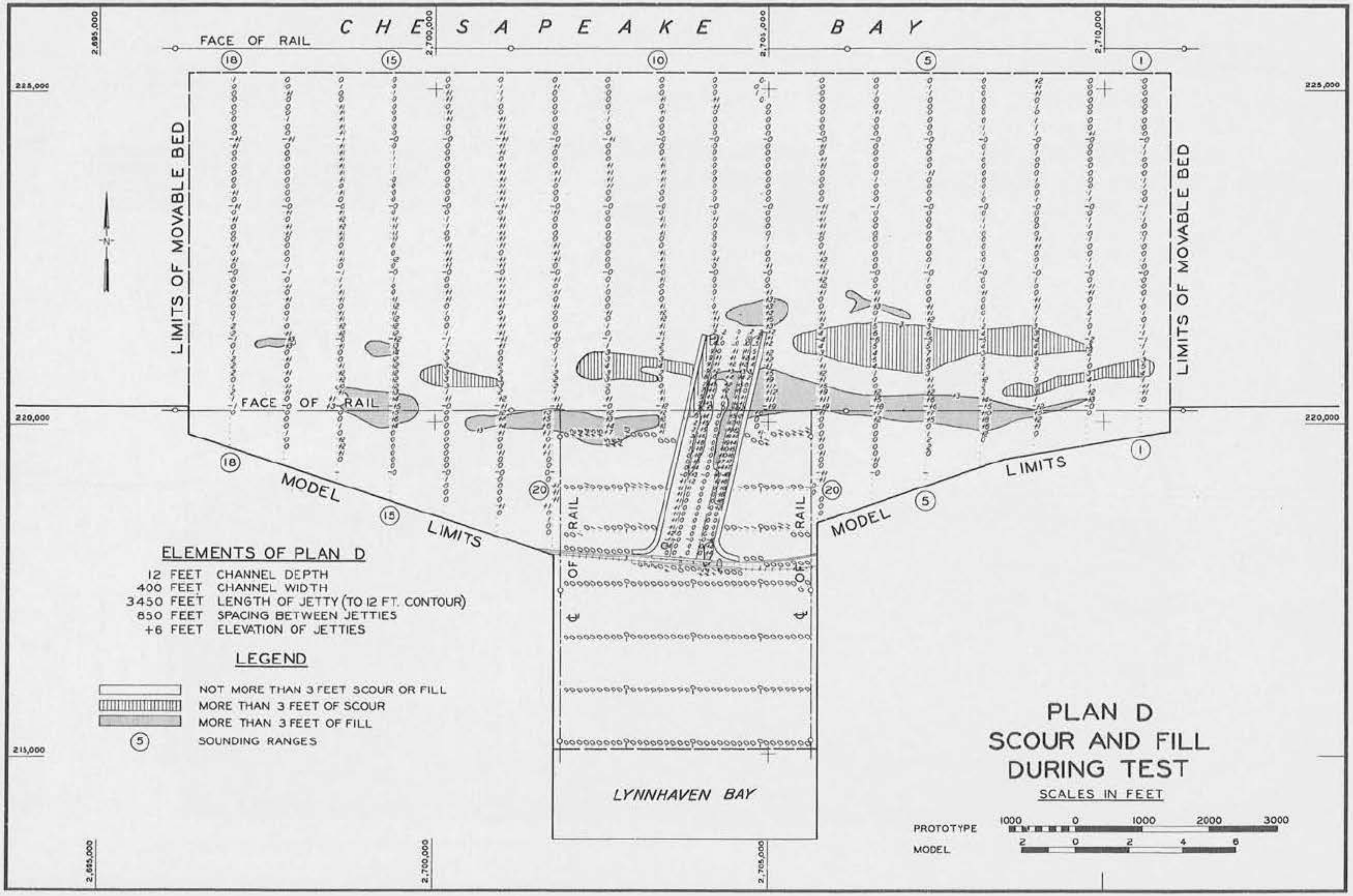
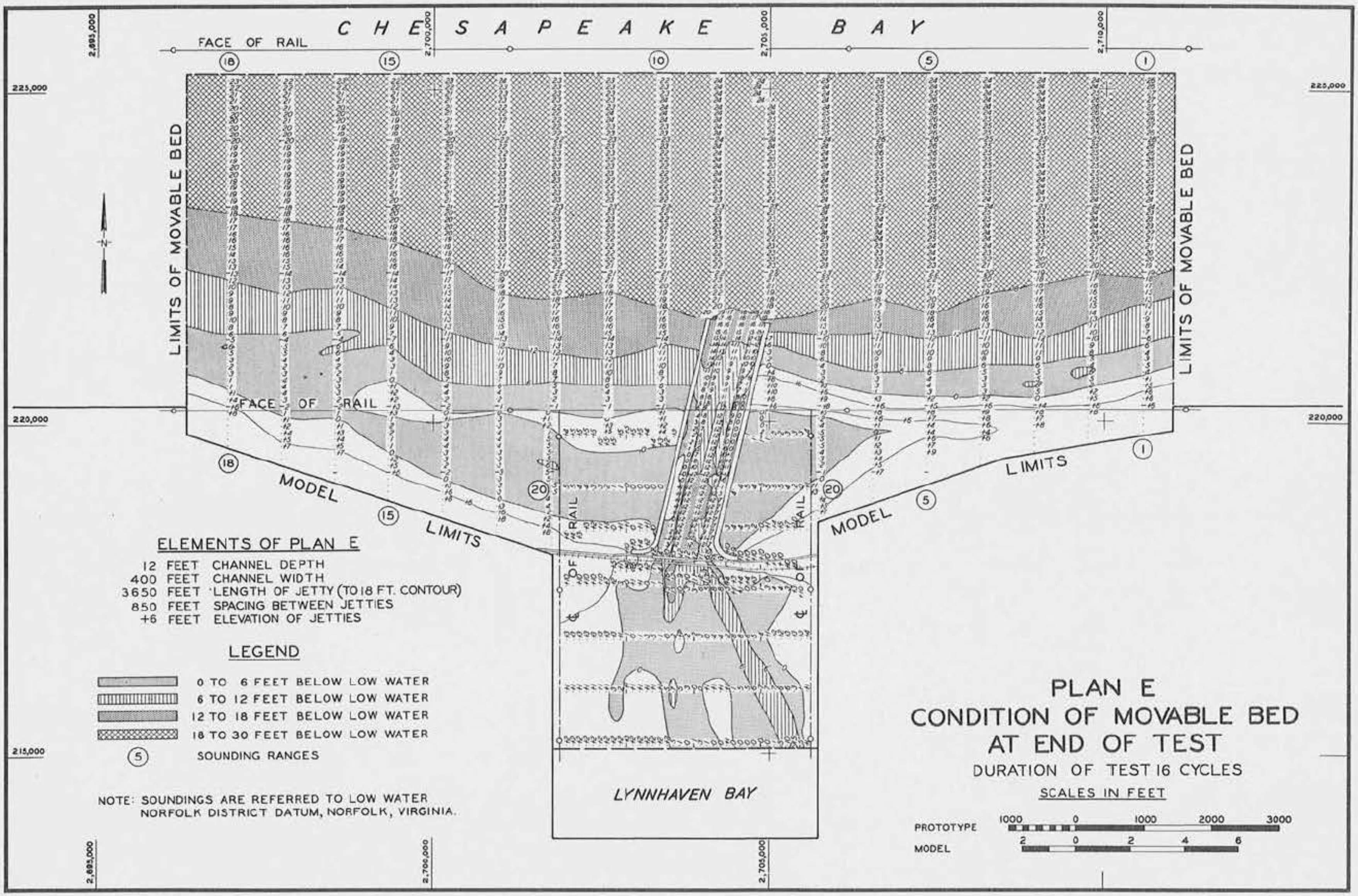

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
N
MODEL LIMITS
℄ OF RAIL
LYNNHAVEN BAY
ELEMENTS OF PLAN D
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3450 FEET LENGTH OF JETTY (TO 12 FT. CONTOUR)
850 FEET SPACING BETWEEN JETTIES
+6 FEET ELEVATION OF JETTIES
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
5 SOUNDING RANGES
PLAN D
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000 3000
MODEL 2 0 2 4 6
2,695,000
2,700,000
2,705,000
2,710,000
225,000
220,000
215,000

PLATE 60



PLAN E
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES

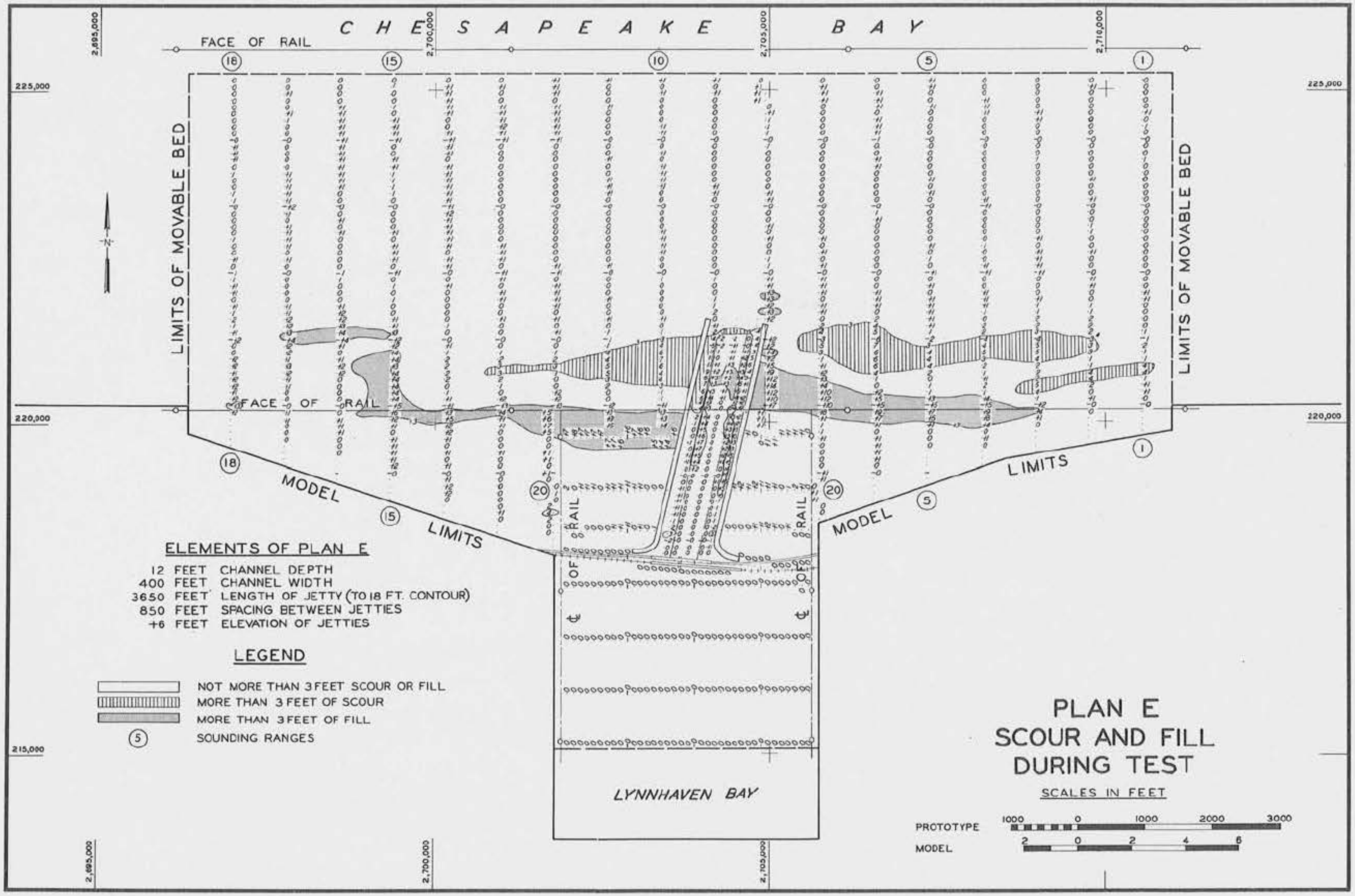
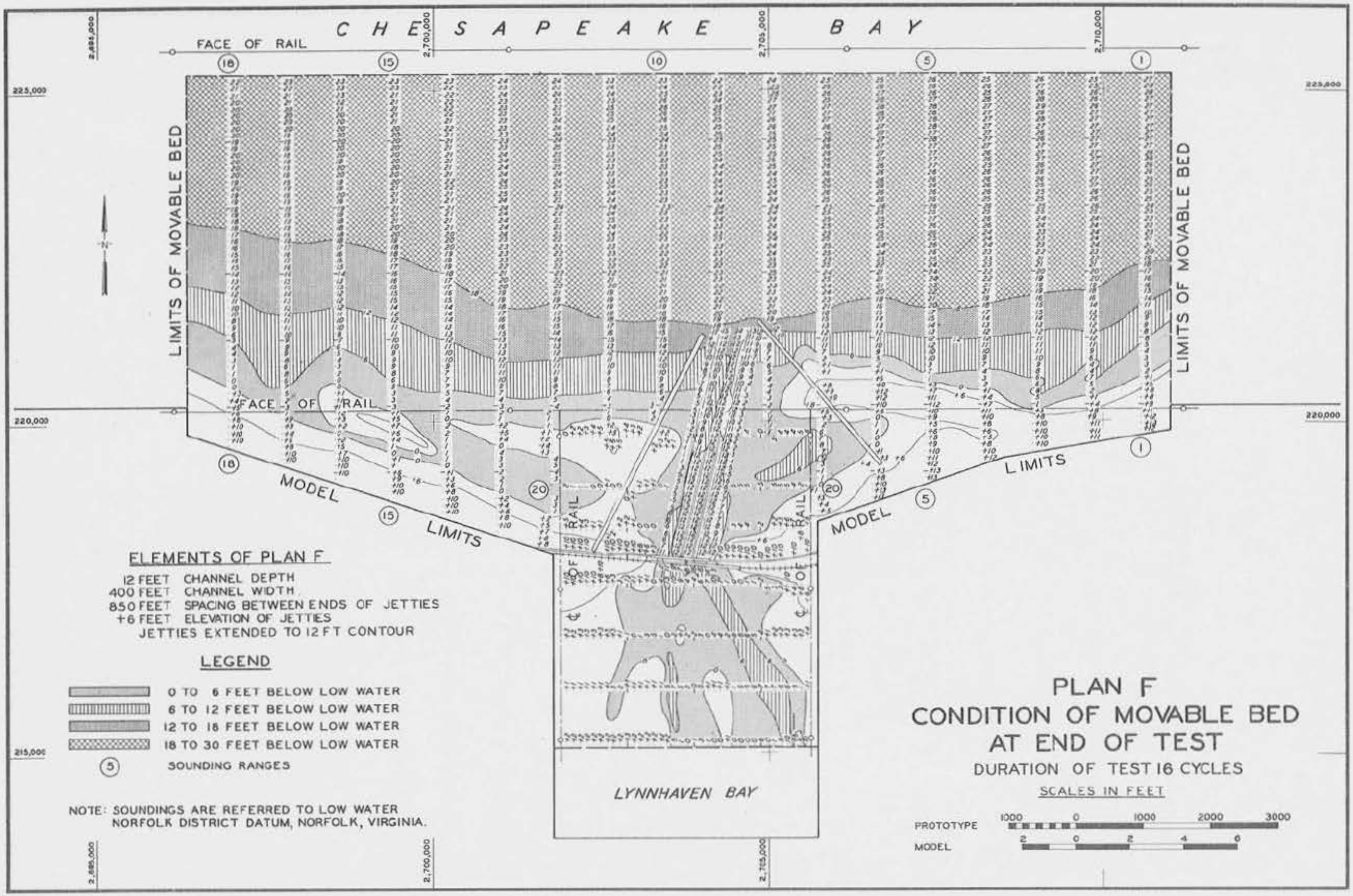

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN E
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3650 FEET LENGTH OF JETTY (TO 18 FT. CONTOUR)
850 FEET SPACING BETWEEN JETTIES
+6 FEET ELEVATION OF JETTIES
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
SOUNDING RANGES
PLAN E
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE
MODEL
225,000
220,000
215,000
2,695,000
2,700,000
2,705,000
2,710,000

PLATE 62

PLATE 63


C H E S A P E A K E B A Y
FACE OF RAIL
LIMITS OF MOVABLE BED
LIMITS OF MOVABLE BED
MODEL LIMITS
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN F
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
850 FEET SPACING BETWEEN ENDS OF JETTIES
+6 FEET ELEVATION OF JETTIES
JETTIES EXTENDED TO 12 FT CONTOUR
LEGEND
0 TO 6 FEET BELOW LOW WATER
6 TO 12 FEET BELOW LOW WATER
12 TO 18 FEET BELOW LOW WATER
18 TO 30 FEET BELOW LOW WATER
SOUNDING RANGES
NOTE: SOUNDINGS ARE REFERRED TO LOW WATER NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.
PLAN F
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES
SCALES IN FEET
PROTOTYPE
1000 0 1000 2000 3000
MODEL
2 0 2 4 6

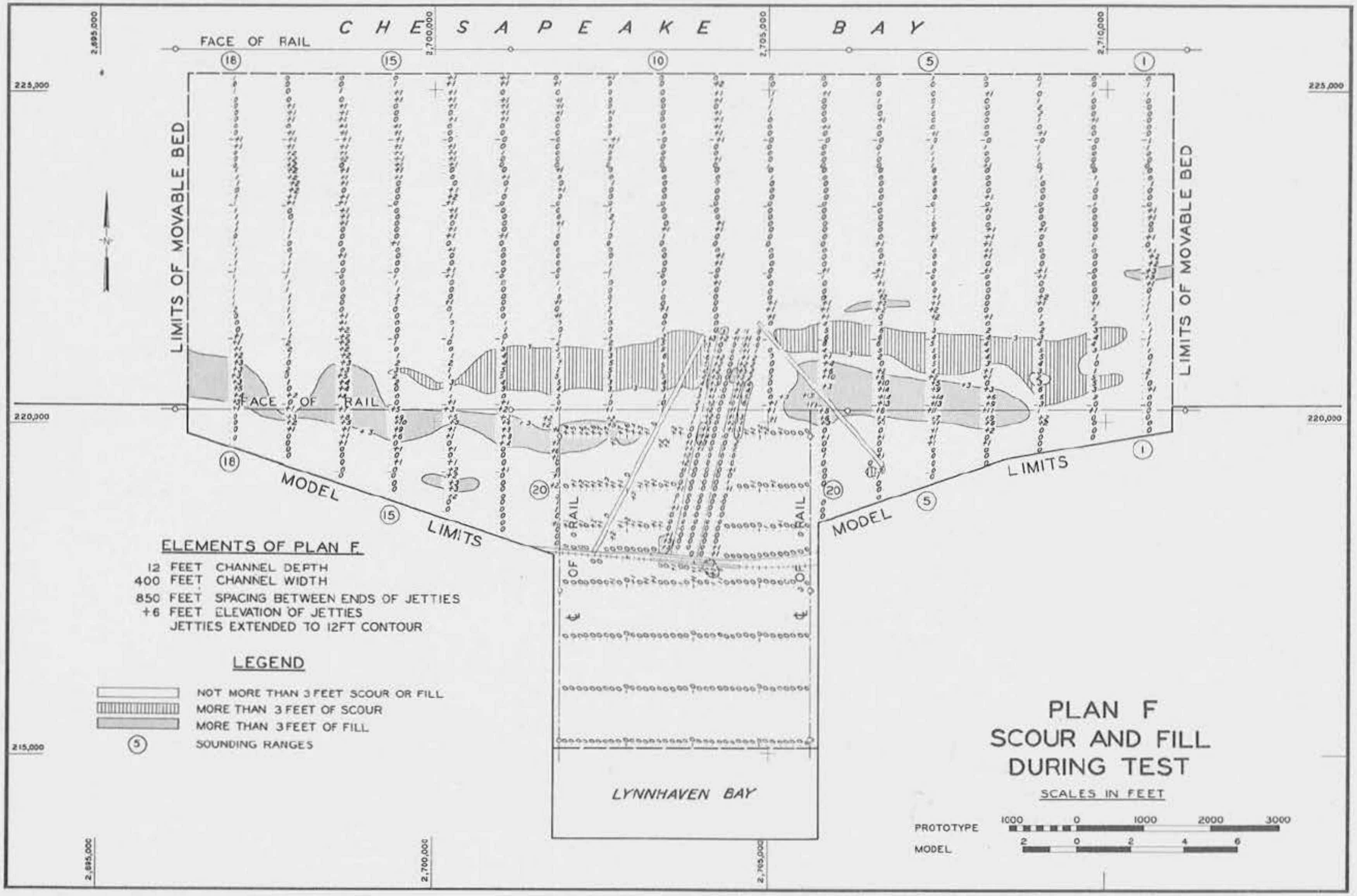
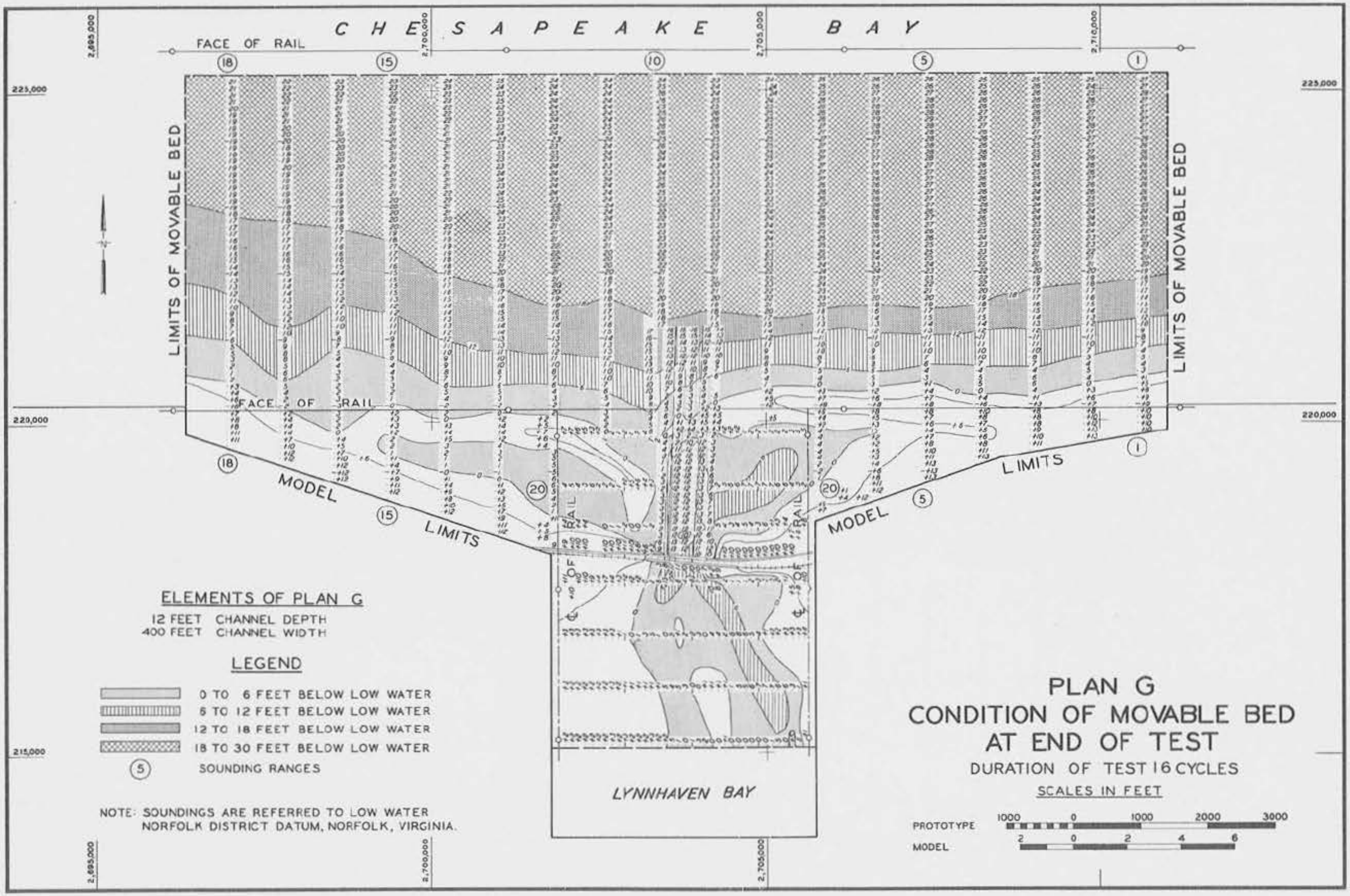

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN F
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
850 FEET SPACING BETWEEN ENDS OF JETTIES
+6 FEET ELEVATION OF JETTIES
JETTIES EXTENDED TO 12FT CONTOUR
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
SOUNDING RANGES
PLAN F
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE
MODEL
2,695,000
2,700,000
2,705,000
2,710,000
225,000
220,000
215,000

PLATE 64

PLATE 65



PLAN G
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES

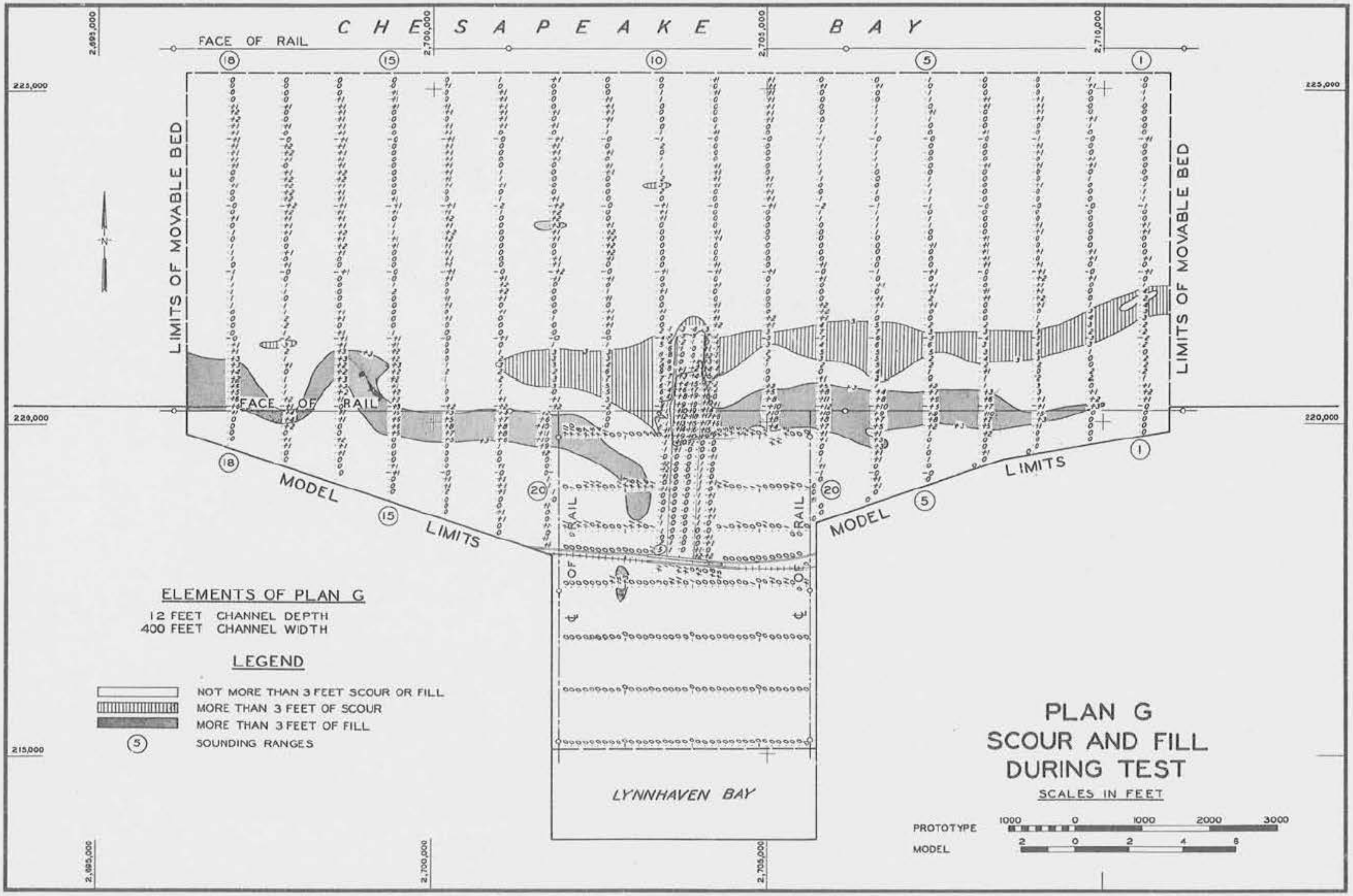
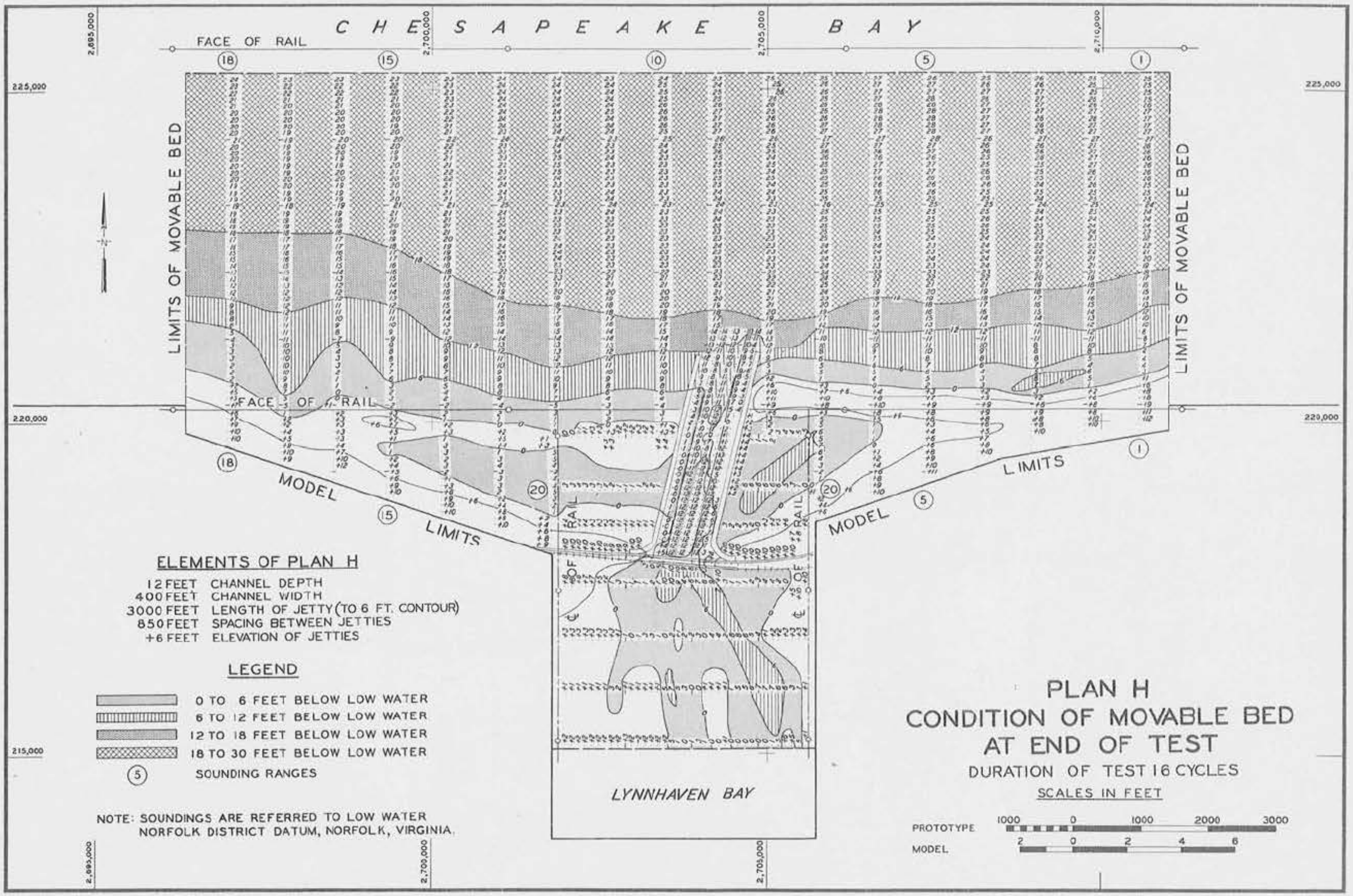

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
LIMITS OF MOVABLE BED
FACE OF RAIL
MODEL LIMITS
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN G
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
SOUNDING RANGES
PLAN G
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE
MODEL
225,000
220,000
215,000
2,695,000
2,700,000
2,705,000
2,710,000

PLATE 66

PLATE 67


CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
LIMITS OF MOVABLE BED
FACE OF RAIL
MODEL LIMITS
MODEL LIMITS
N
LYNNHAVEN BAY
2,695,000
2,700,000
2,705,000
2,710,000
225,000
220,000
215,000
ELEMENTS OF PLAN H
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3000 FEET LENGTH OF JETTY (TO 6 FT. CONTOUR)
850 FEET SPACING BETWEEN JETTIES
+6 FEET ELEVATION OF JETTIES
LEGEND
0 TO 6 FEET BELOW LOW WATER
6 TO 12 FEET BELOW LOW WATER
12 TO 18 FEET BELOW LOW WATER
18 TO 30 FEET BELOW LOW WATER
5 SOUNDING RANGES
NOTE: SOUNDINGS ARE REFERRED TO LOW WATER
NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.
PLAN H
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000 3000
MODEL 2 0 2 4 6

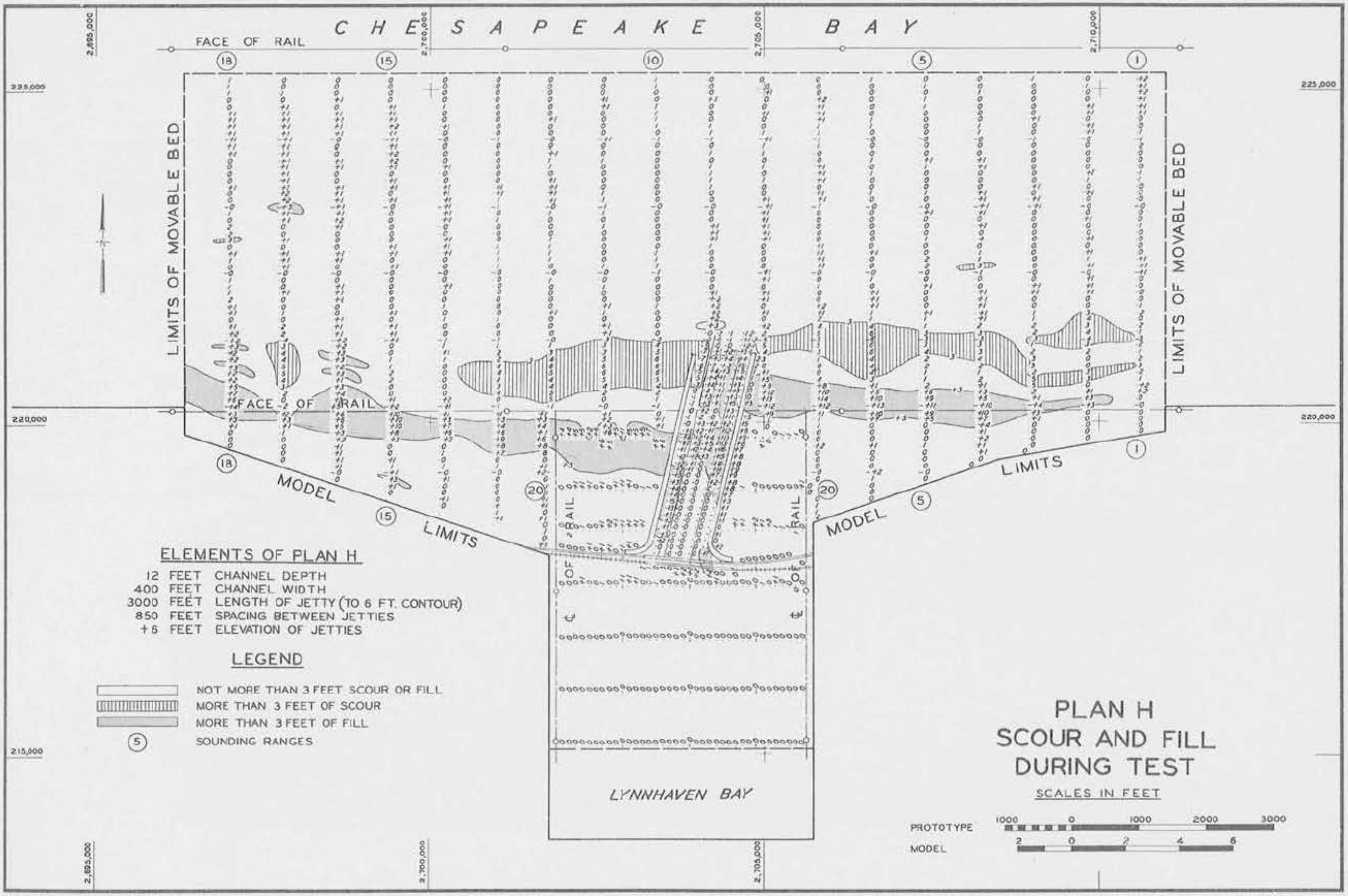
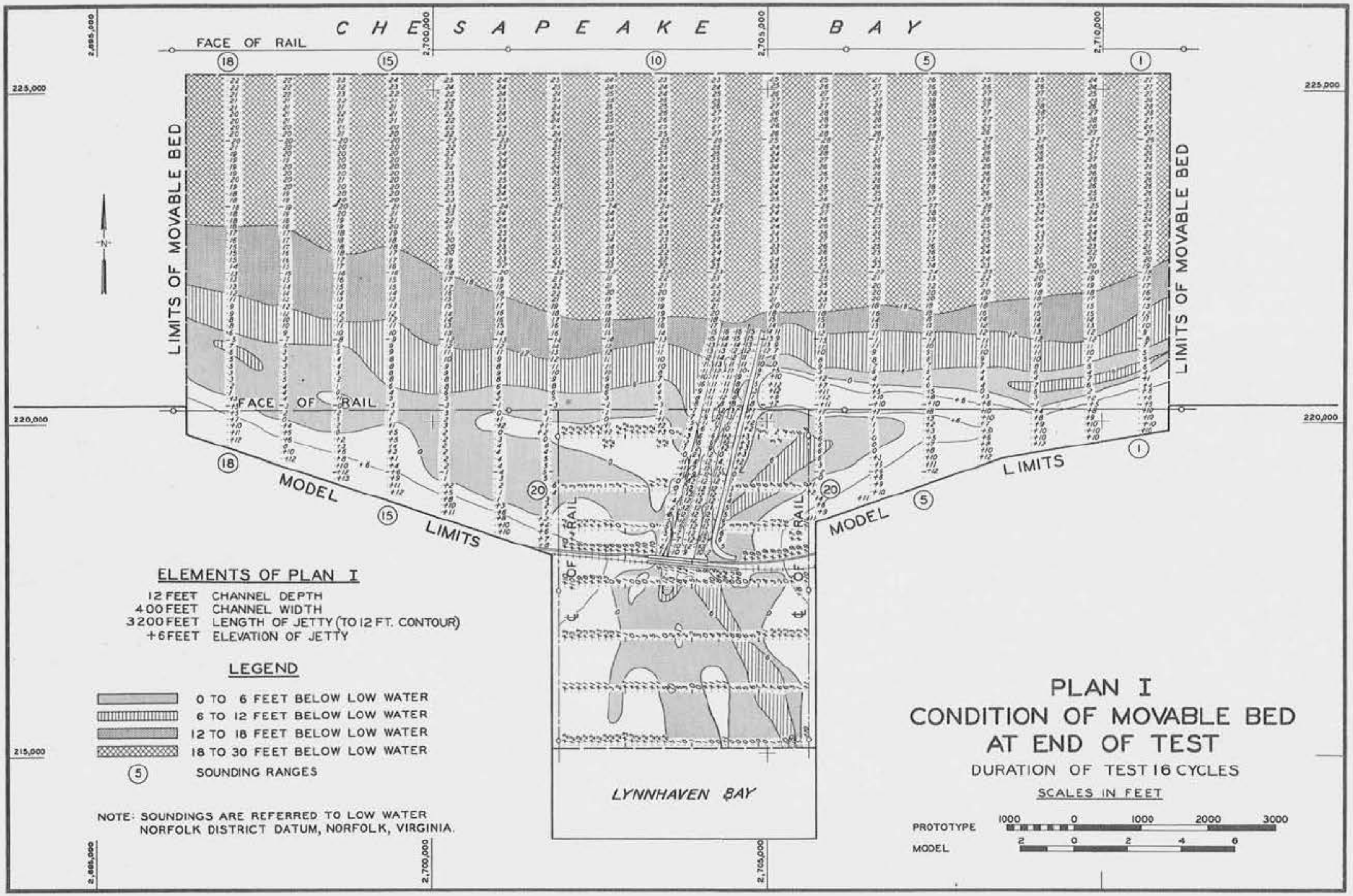

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN H
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3000 FEET LENGTH OF JETTY (TO 6 FT. CONTOUR)
850 FEET SPACING BETWEEN JETTIES
+6 FEET ELEVATION OF JETTIES
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
SOUNDING RANGES
PLAN H
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE
MODEL

PLATE 68


CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN I
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3200 FEET LENGTH OF JETTY (TO 12 FT. CONTOUR)
+6 FEET ELEVATION OF JETTY
LEGEND
0 TO 6 FEET BELOW LOW WATER
6 TO 12 FEET BELOW LOW WATER
12 TO 18 FEET BELOW LOW WATER
18 TO 30 FEET BELOW LOW WATER
(5) SOUNDING RANGES
NOTE: SOUNDINGS ARE REFERRED TO LOW WATER NORFOLK DISTRICT DATUM, NORFOLK, VIRGINIA.
PLAN I
CONDITION OF MOVABLE BED AT END OF TEST
DURATION OF TEST 16 CYCLES
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000 3000
MODEL 2 0 2 4 6
225,000
220,000
215,000
2,695,000
2,700,000
2,705,000
2,710,000

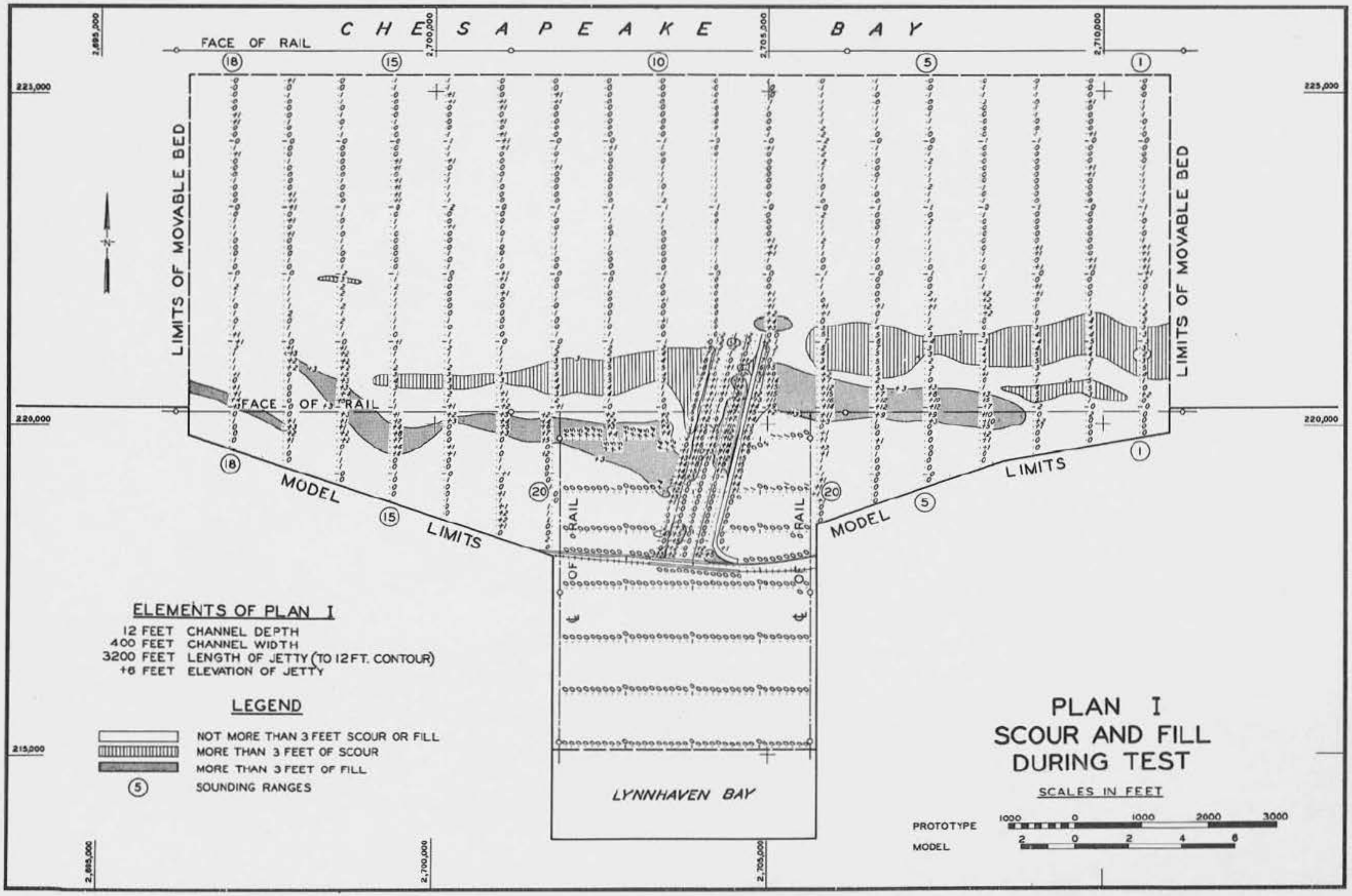
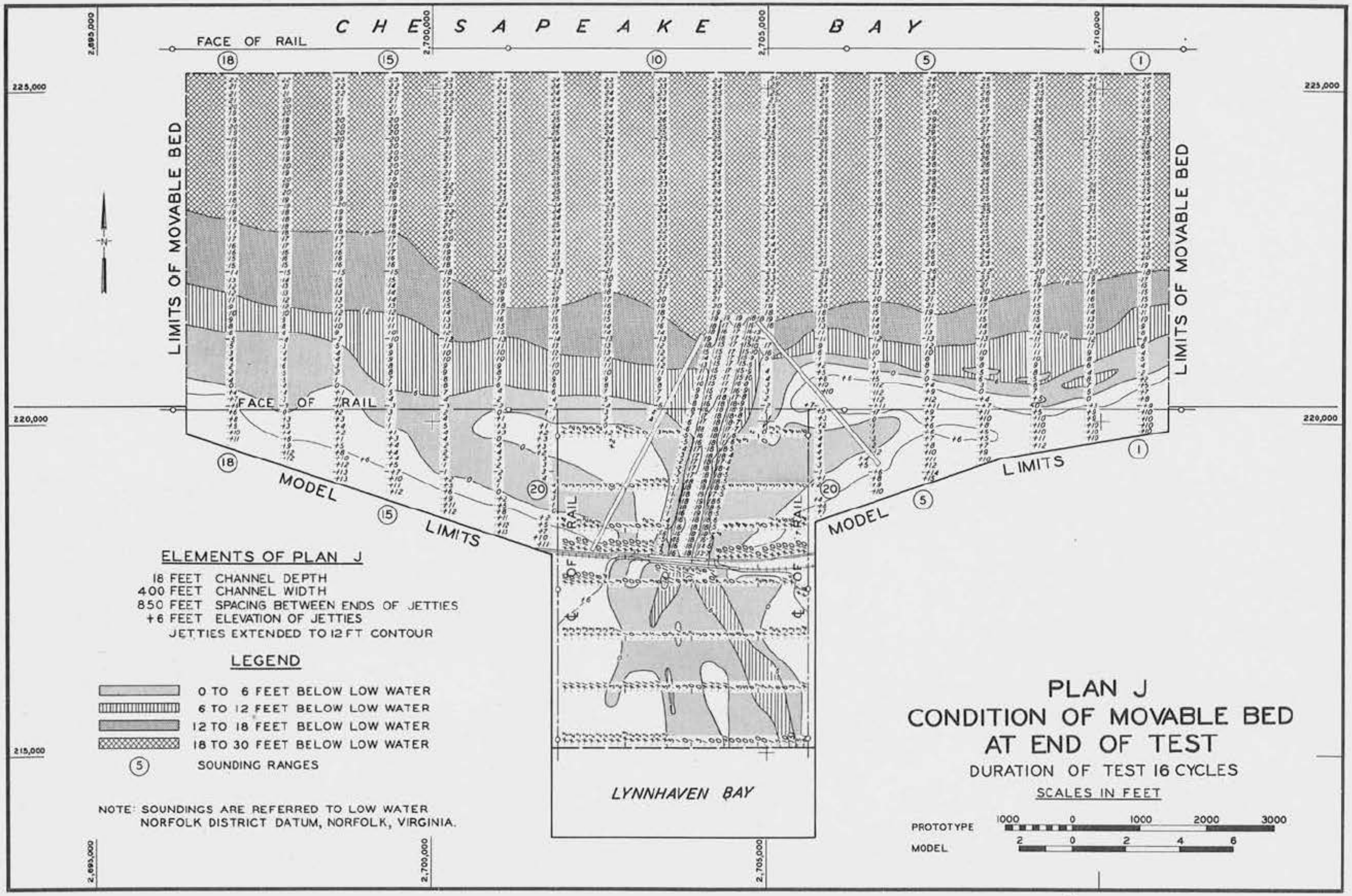

C H E S A P E A K E B A Y
FACE OF RAIL
LIMITS OF MOVABLE BED
LIMITS OF MOVABLE BED
FACE OF RAIL
MODEL LIMITS
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN I
12 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
3200 FEET LENGTH OF JETTY (TO 12 FT. CONTOUR)
+6 FEET ELEVATION OF JETTY
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
SOUNDING RANGES
PLAN I
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000 3000
MODEL 2 0 2 4 6
225,000
220,000
215,000
2,695,000
2,700,000
2,705,000
2,710,000

PLATE 70

PLATE 71



PLAN J
CONDITION OF MOVABLE BED
AT END OF TEST
DURATION OF TEST 16 CYCLES

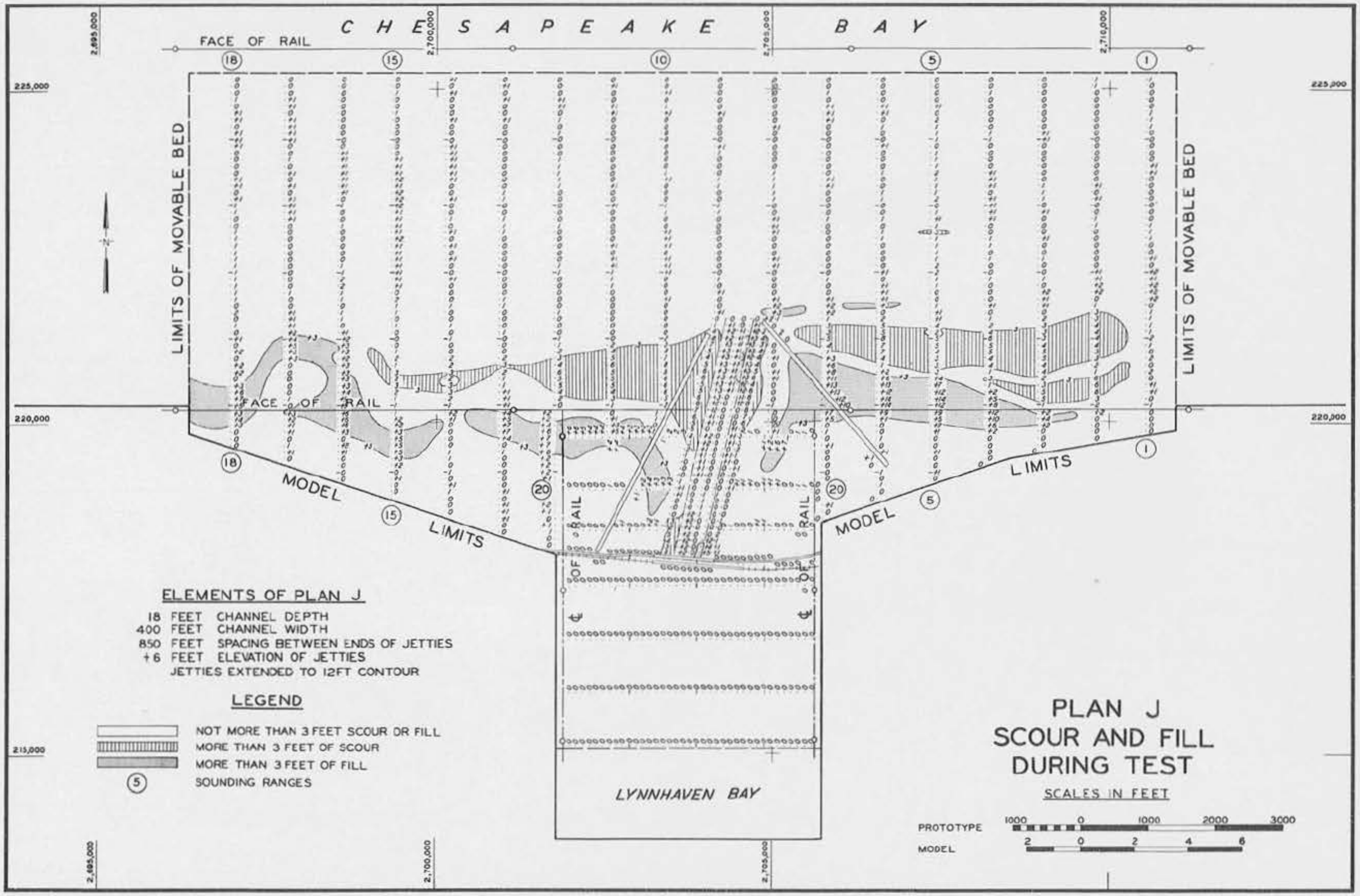

CHESAPEAKE BAY
FACE OF RAIL
LIMITS OF MOVABLE BED
MODEL LIMITS
LYNNHAVEN BAY
ELEMENTS OF PLAN J
18 FEET CHANNEL DEPTH
400 FEET CHANNEL WIDTH
850 FEET SPACING BETWEEN ENDS OF JETTIES
+6 FEET ELEVATION OF JETTIES
JETTIES EXTENDED TO 12FT CONTOUR
LEGEND
NOT MORE THAN 3 FEET SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
MORE THAN 3 FEET OF FILL
SOUNDING RANGES
PLAN J
SCOUR AND FILL
DURING TEST
SCALES IN FEET
PROTOTYPE
MODEL
225,000
220,000
215,000
2,695,000
2,700,000
2,705,000
2,710,000

PLATE 72